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Proposed Best Demonstrated Available Technology (BDAT) Background Document for K031, K084, K101, K102, Characteristic Arsenic Wastes (D004), Characteristic Selenium Wastes (D010), and P and U Wastes Containing Arsenic and Selenium Listing Constitutents. Volume 1

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BEST DEMONSTRATED AVAILABLE TECHNOLOGY (BDAT) BACKGROUND DOCUMENT FOR K031, K084, K101, K102, CHARACTERISTIC ARSENIC WASTES (D004), CHARACTERISTIC SELENIUM WASTES (D010), AND P AND U WASTES CONTAINING ARSENIC AND SELENIUM LISTING CONSTITUENTS

Larry Rosengrant, Chief
Treatment Technology Section

Rhonda Craig
Project Manager

U.S. Environmental Protection Agency
Office of Solid Waste
401 M. Street, S.W.
Washington, D.C. 20460

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TABLE OF CONTENTS

		Page No.
EXECUTIVE SUMMARY		E-1
1.	INDUSTRIES AFFECTED AND WASTE CHARACTERIZATION	1-1
	1.1 Industries Affected	1-2
	1.1.1 Industries Producing and Using Arsenic and Its Compounds	1-3
	1.1.2 Industries Producing and Using Selenium and Its Compounds	1-4
	1.1.3 Processes That Generate Arsenic-Containing Wastes	1-5
	1.1.4 Processes That Generate Selenium-Containing Wastes	1-7
	1.2 Waste Characterization	1-8
	1.2.1 Arsenic	1-8
	1.2.2 Selenium	1-10
	1.3 Determination of Waste Treatability Group	1-10
2.	APPLICABLE AND DEMONSTRATED TREATMENT TECHNOLOGIES	2-1
	2.1 Applicable Treatment Technologies	2-1
	2.1.1 Nonwastewaters	2-2
	2.1.2 Wastewaters	2-5
	2.2 Demonstrated Technologies	2-8
	2.2.1 Demonstrated Technologies for Nonwastewaters	2-8
	2.2.2 Demonstrated Technologies for Wastewaters	2-11
3.	PERFORMANCE DATA BASE	3-1
	3.1 Performance Data Base for Nonwastewaters	3-1
	3.1.1 Incineration Performance Data	3-2
	3.1.2 Stabilization Performance Data	3-3
	3.1.3 Vitrification Performance Data	3-5
	3.2 Performance Data Base for Wastewaters	3-6
	3.2.1 Chemical Precipitation Performance Data	3-6
4.	IDENTIFICATION OF BEST DEMONSTRATED AVAILABLE TECHNOLOGY (BDAT)	4-1
	4.1 Nonwastewaters	4-1
	4.2 Wastewaters	4-4

TABLE OF CONTENTS (continued)

Page No.

5. SELECTION OF REGULATED CONSTITUENTS 5-1

6. CALCULATION OF BDAT TREATMENT STANDARDS 6-1

6.1 Arsenic Nonwastewaters 6-1
6.1.1 D004, K031, K084, P010, P011, P012, P036, P038, and U136 Nonwastewaters 6-1
6.1.2 K101 and K102 Nonwastewaters 6-2

6.2 Arsenic Wastewaters 6-2
6.2.1 D004, K031, K084, P010, P011, P012, P036, P038, and U136 Wastewaters 6-3
6.2.2 K101 and K102 Wastewaters 6-4

6.3 Selenium Nonwastewaters 6-5
6.3.1 D010, P103, P114, U204, and U205 Nonwastewaters. 6-5

6.4 Selenium Wastewaters 6-6
6.4.1 D010, P103, P114, U204, and U205 Wastewaters .. 6-6

7. REFERENCES 7-1

APPENDIX A - INDUSTRY INFORMATION AND CHARACTERIZATION DATA FOR ARSENIC AND SELENIUM A-1

APPENDIX B - HIGH TEMPERATURE STABILIZATION TECHNOLOGIES B-1

B-1 Applicability B-1

B-2 Underlying Principles of Operation B-2
B.2.1 Glass Vitrification B-2
B.2.2 Slag Vitrification B-3
B.2.3 High-Temperature Calcination B-3

B-3 Description of the High-Temperature Stabilization Processes B-4
B.3.1 Glass Vitrification B-4
B.3.2 Slag Vitrification B-5
B.3.3 High-Temperature Calcination B-5

TABLE OF CONTENTS (continued)

Page No.

B.4 Waste Characteristics Affecting Performance (WCAPs).... B-6
B.4.1 Waste Characteristics Affecting Performance of Vitrification Processes..... B-6
B.4.2 Waste Characteristics Affecting Performance of High-Temperature Calcination..... B-8

B.5 Design and Operating Parameters..... B-9
B.5.1 Design and Operating Parameters for Vitrification Processes..... B-9
B.5.2 Design and Operating Parameters for High-Temperature Calcination Systems..... B-12

B.6 References..... B-13

APPENDIX C - TREATMENT PERFORMANCE DATA BASE FOR ARSENIC AND SELENIUM WASTES..... C-1

APPENDIX D - ANALYTICAL METHODS AND QUALITY ASSURANCE/QUALITY CONTROL DATA..... D-1

LIST OF TABLES

Table No.		Page No.
1	Proposed Treatment Standards for Arsenic-Containing and Selenium-Containing Wastes	E-3
6-1	Calculation of Treatment Standards for Arsenic	6-7
6-2	Calculation of Metal Treatment Performance Standards for K101 and K102 Wastewaters	6-7
A-1	Current Manufacturers of Arsenic and Selenium Compounds.	A-1
A-2	Characterization Data For D004 Characteristic Arsenic Wastes	A-2
A-3	Waste Characterization Data for K031	A-4
A-4	Waste Characterization Data for K084	A-5
A-5	Waste Characterization Data for K101 and K102	A-6
A-6	Waste Characterization Data for P010, P011, and P012 Wastes	A-7
A-7	Characterization Data for D010 Characteristic Selenium Wastes	A-8
B-1	Metal Hydroxide Decomposition Temperatures	B-12
C-1	Stabilization Treatment Performance Data for Arsenic Wastes	C-1
C-2	Stabilization Treatment Performance Data for K031	C-2
C-3	Stabilization Treatment Performance Data for Proprietary Process	C-3
C-4	Effect of the pH on the Stability of Ferric Arsenate Precipitates	C-4
C-5	EP-Toxicity Testing of Calcium Arsenate-Containing and Calcium Selenate-Containing Precipitates	C-5
C-6	Performance Data for the Stability of Calcium Arsenate, Manganese Arsenate, and Ferric Arsenate Precipitates	C-6

LIST OF TABLES (Continued)

Table No.		Page No.
C-7	Vitrification Treatment Performance Data for Slags Containing Arsenic	C-7
C-8	Vitrification/Glassification Treatment Performance Data.	C-8
C-9	Precipitation Treatment Performance Data for D004 Wastewaters	C-9
C-10	Ferric Arsenate Precipitation Treatment Performance Data for Different Iron-to-Arsenic Ratios	C-14
C-11	Selenium Removal from Wastewaters by Chemical Reduction with Ferrous Ion	C-15
D-1	Analytical Methods for Regulation Constituents	D-2
D-2	Specific Procedures or Equipment Used in Preparation for Analysis of Metals When Alternatives or Equivalents Are Allowed in the SW-846 Methods	D-3
D-3	Matrix Spike Recoveries for Treated D004 Waste	D-4
D-4	Matrix Spike Recoveries Used to Calculate Correction Factors for the Slag Vitrification EP-Tox Leachate Value	D-5

EXECUTIVE SUMMARY

Pursuant to section 3004(m) of the Hazardous and Solid Waste Amendments (HSWA), enacted on November 8, 1984, the Environmental Protection Agency (EPA) is proposing treatment standards based on best demonstrated available technology (BDAT) for certain wastes containing arsenic and selenium. The arsenic-containing wastes are D004, K031, K084, P010, P011, P012, P036, P038, and U136. The selenium-containing wastes are D010, P103, P114, U204, and U205. Additionally, the Agency is proposing to change the nonwastewater treatment standards for K101 and K102, which were promulgated on August 17, 1988, by eliminating the low and high level arsenic subcategories. The low level standards were originally based on incineration as BDAT. This background document presents the development of new treatment performance standards based on vitrification as BDAT. Additionally, the Agency is proposing to change the treatment standards for K101 and K102 wastewaters because of the discovery of an improperly operated component of the wastewater system used to develop the standards.

It is important to mention that although the nonwastewater performance standards for arsenic and selenium are based on vitrification as the BDAT, the regulated community is not required to use vitrification, but may use other technologies that can achieve the performance standards. Moreover, the Agency wants to remind the regulated community that it encourages recycle/recovery whenever applicable for a waste stream.

The BDAT proposed treatment standards for wastewater and nonwastewater forms of the wastes listed above are summarized in Table 1. A wastewater is defined by the Agency as containing less than 1 percent (weight basis) total suspended solids and less than 1 percent (weight basis) total organic carbon. Wastes not meeting this definition must comply with the treatment standards for nonwastewaters. Compliance with these treatment standards is a prerequisite for placement of these wastes in facilities

designated as land disposal units according to 40 CFR Part 268. The effective date of these proposed treatment standards is May 8, 1990.

This background document presents the Agency's technical support and rationale for developing regulatory standards for these wastes. Section 1 presents available data regarding the industries affected by the land disposal restriction, brief descriptions of the waste-generating processes, and waste characterization data. Section 2 discusses the technologies used to treat the wastes, and Section 3 presents available treatment performance data, including the data upon which the treatment standards are based. Section 4 explains EPA's determination of BDAT, while Section 5 discusses the selection of constituents to be regulated. Proposed treatment standards are determined in Section 6.

EPA wishes to point out that, because of facility claims of confidentiality, this document does not contain all of the data that EPA used in its regulatory decision-making process. Under 40 CFR Part 2, Subpart B, facilities may claim any or all of the data that are submitted to EPA as confidential. EPA will make determinations regarding the validity of the facility's claim of confidential business information (CBI) according to 40 CFR Part 2, Subpart B. In the meantime, the Agency will treat the data as CBI. Additionally, the Agency would like to emphasize that it evaluated all available data (including CBI data) in developing the BDAT treatment standards for the arsenic- and selenium-containing wastes described in this background document.

The BDAT program and promulgated methodology are more thoroughly described in two additional documents: Methodology for Developing BDAT Treatment Standards (USEPA 1988c) and Generic Quality Assurance Project Plan for the Land Disposal Restrictions Program (BDAT) (USEPA 1988b). The petition process to be followed in requesting a variance from BDAT treatment standards is discussed in the methodology document.

Table 1 Proposed Treatment Standards for Arsenic-Containing and Selenium-Containing Wastes

Waste code	Regulated constituent	Total composition		Nonwastewater leachate
		Nonwastewater (mg/kg)	Wastewater (mg/l)	EP-Toxicity (mg/l)
D004	Arsenic	NA	0.79	5.6
D010	Selenium	NA	0.79	5.6
K031	Arsenic	NA	0.79	5.6
K084	Arsenic	NA	0.79	5.6
K101	2-Nitroaniline	14	0.27	NA
	Arsenic	NA	0.79	5.6
	Cadmium	NA	0.24	NA
	Lead	NA	0.17	NA
	Mercury	NA	0.082	NA
K102	Ortho-nitrophenol	13	0.028	NA
	Arsenic	NA	0.79	5.6
	Cadmium	NA	0.24	NA
	Lead	NA	0.17	NA
	Mercury	NA	0.082	NA
P010	Arsenic	NA	0.79	5.6
P011	Arsenic	NA	0.79	5.6
P012	Arsenic	NA	0.79	5.6
P036	Arsenic	NA	0.79	5.6
P038	Arsenic	NA	0.79	5.6
P103	Selenium	NA	0.79	5.6
P114*	Selenium	NA	0.79	5.6
U136	Arsenic	NA	0.79	5.6
U204	Selenium	NA	0.79	5.6
U205	Selenium	NA	0.79	5.6

NA - Not Applicable.

*This waste is also regulated for thallium see USEPA 1989c.

1. INDUSTRIES AFFECTED AND WASTE CHARACTERIZATION

This section presents available information about the industries that will be affected and the available characterization data for the wastes discussed in this document. The arsenic- and selenium-bearing wastes discussed in this document are listed by the Agency according to 40 CFR 261 as follows:

D004 - Characteristic arsenic
P010 - Arsenic acid
P011 - Arsenic trioxide
P012 - Arsenic pentoxide
P036 - Dichlorophenyl arsine
P038 - Diethyl arsine
U136 - Cacodylic acid
K031 - By-product salts generated in the production of monosodium methanearsonate (MSMA) and cacodylic acid
K084 - Wastewater treatment sludge generated during production of veterinary pharmaceuticals from arsenic or organoarsenic compounds
K101 - Distillation tar residues from the distillation of aniline-based compounds in the production of veterinary pharmaceuticals from arsenic or organoarsenic compounds
K102 - Residue from the use of activated carbon for decolorizing in the production of veterinary pharmaceuticals from arsenic or organoarsenic compounds
D010 - Characteristic selenium
P103 - Selenourea
P114 - Thallium selenite
U204 - Selenium dioxide
U205 - Selenium disulfide

The K-codes are for wastes from specific sources. The D-codes are for wastes that exhibit the characteristic of EP toxicity. That is, a D004 waste has a leachate concentration (based on the EP-toxicity test) greater than or equal to 5.0 mg/l arsenic, and a D010 waste has a concentration greater than or equal to 1.0 mg/l selenium in the leachate, using the EP-toxicity test. The hazardous wastes with P-codes are identified as acute hazardous wastes, while the hazardous waste codes

beginning with U identify toxic wastes. In essense, constituents in P and U code wastes are only hazardous if they are discarded commercial products, or spilled commercial products. P and U constituents that are normally contained in process waste streams are not hazardous wastes unless they are determined to be D, F, or K wastes.

The Agency has determined that these hazardous wastes represent a single treatability group based on their similar chemical characteristics. As described later in this section, EPA examined the sources of the wastes, the specific similarities in waste composition, applicable and demonstrated technologies, and attainable treatment performance in order to support the regulatory approach for these wastes.

1.1 Industries Affected

Because of the diverse nature and magnitude of industries generating D004 and D010, EPA has not attempted to describe every industry that could generate these wastes. Additionally, the Agency does not intend to describe every industry that generates the P and U wastes containing arsenic and selenium listing constituents, since any industrial facility that produces, uses, stores, and/or transports chemicals containing these constituents has the potential of generating the wastes. For the process-specific wastes (i.e., K031, K084, K101, and K102) the industries generating these wastes can be described accurately. The following information is a summary of data in the National Survey of Treatment, Storage, Disposal, and Recycle (TSDR) Facilities (the TSDR Survey), the National Survey of Hazardous Waste Generators (Generator Survey), and related literature (i.e., Bureau of Mines Mineral Yearbook and Mineral Commodity Summaries). The known producers of arsenic and selenium compounds are presented in Table A-1 found in Appendix A.

1.1.1 Industries Producing and Using Arsenic and Its Compounds

The primary commercial source of arsenic is arsenic oxide, As_2O_3, which is generally recovered from flue dusts generated by copper and lead smelters processing arsenopyritic ores. Currently, no smelters in the United States both produce and market arsenic oxide. One facility, Asarco, in Tacoma, Washington, did produce and market arsenic oxide until it ceased production in 1985. Asarco continues to market the arsenic trioxide from earlier production. The remainder of the arsenic oxide consumed in the United States is imported. Approximately 30,000 metric tons of arsenic oxide, 600 metric tons of arsenic metal, and 1,100 metric tons of arsenic compounds (e.g., arsenic sulfide, arsenic acid, sodium arsenate, and lead arsenate) were consumed in the United States in 1988. The estimated end-use distribution of arsenic in 1988 was 69 percent in wood preservatives, 23 percent in agricultural chemicals (principally herbicides and desiccants), 4 percent in glass, 2 percent in nonferrous alloys, and 2 percent in other uses.

Most of the arsenic trioxide consumed is converted to arsenic acid for use in the production of arsenical wood preservatives mainly by five companies. Chromated copper arsenate, by far the most important of the arsenical wood preservatives, is a waterborne, leach-resistant wood preservative prepared by mixing arsenic acid with copper oxide or sulfate and chromic acid. It is used to pressure treat a variety of wood products that are subject to outdoor or inground exposure, and may serve to extend the service life of wood by a factor of at least 15.

The principal agricultural market for arsenicals is in cotton growing, where arsenic acid was used as a desiccant to aid in mechanical stripper harvesting of cotton; other arsenical chemicals, such as monosodium methanearsonate and disodium methanearsonate, were used as herbicides for control of grassy and broadleaf weeds. To a lesser extent, arsenical herbicides were used in noncrop areas such as railroad rights-of-way.

Arsenic trioxide and arsenic acid are used in the glass industry primarily as fining agents to remove tiny, dispersed air bubbles, and also as decolorizing agents. Use in recent years has been limited to the pressed and blown glass sector for products such as tableware, lead glass, optical glass, and glass ceramics.

The bulk of metallic arsenic is used in lead- and copper-based alloys as a minor additive (about 0.01 to 0.5 percent) to increase strength in the posts and grids of lead-acid storage batteries and to improve corrosion resistance and tensile strength in copper alloys.

High-purity arsenic metal is used in the electronics industry. Gallium arsenide and its alloys have been used in such products as light-emitting diodes and displays, room-temperature lasers, microwave devices, solar cells, and photoemissive surfaces. Gallium arsenide integrated circuits, currently undergoing commercial development, have, compared with silicon circuits, higher operating frequencies, lower power consumption, lower noise, and superior resistance to radiation damage. Because of these superior properties, they are expected to have extensive military and commercial applications.

1.1.2 Industries Producing and Using Selenium and Its Compounds

Elemental selenium is recovered from anode slimes as a by-product of electrolytic copper refining at five copper refineries. In 1988, approximately 280 metric tons of selenium were produced and 660 metric tons were consumed in the United States. There was no reported domestic production of secondary selenium; however, scrap xerographic materials containing selenium were exported to Canada and the United Kingdom for processing to recover selenium. The estimated consumption of selenium by end use in 1988 is as follows: electronic and photocopier components, 43 percent; glass manufacturing, 20 percent; chemical and pigments, 20 percent; and other, including metallurgy and agriculture, 17 percent.

Almost half of the selenium produced is used by the electronic industry. The major electronic use of elemental selenium is as a photoreceptor in plain paper electrophotographic copiers.

The U.S. automobile and construction industries contributed to a strong demand for selenium-containing pigments. These pigments, which range in color from light orange to maroon, depending on the selenium content, have good heat stability and are important colorants for plastics, glass, and ceramics. The chief pigment produced is cadmium red, a double salt of cadmium sulfide and cadmium selenide.

The primary use of selenium in the glass industry in 1986 was in container glass, where it was used to decolor the yellow-green tint imparted by ferrous ions. Also, selenium is used in architectural plate glass, where it is used in combination with cobalt oxide and iron oxide to reduce solar heat transmission.

The major chemical manufactured is selenic acid, which is produced via a selenium dioxide intermediate. Selenic acid is used chiefly as an additive to bright copper and bright chromium electroplating baths. Lesser amounts of selenic acid are consumed to manufacture inorganic selenate salts, which are used at trace levels as soil nutrients. Production volumes of selenic acid and its salts are low, averaging only a few hundred pounds per year for the past few years (King 1989). Research amounts of organoselenium compounds are produced using selenic acid as a feedstock material.

1.1.3 Processes That Generate Arsenic-Containing Wastes

Arsenic wastes generated in 1985 (USEPA 1987c) were as follows: 38,538 tons of D004, 12,571 tons of K031, 891 tons of K084, 117 tons of K101, 278 tons of K102, 72 tons of P010, 1.4 tons of P011, 345 tons of

P012, 24 tons of P038, and 1.0 ton of U136. No P036 was generated in 1985. This section describes the potential generating processes for these wastes.

As stated earlier, the largest consumption of arsenic oxide is for the production of inorganic arsenates for use as wood preservatives. The generalized production process involves oxidation of arsenic trioxide to arsenic acid and then reaction of the arsenic acid with an oxide or carbonate metal salt. The product precipitates from solution, is collected by filtration, and then is washed, dried, and packaged. Subsequent treatment of wastewaters from these processes generates nonwastewaters containing metal arsenates. Furthermore, use of arsenate salts for wood impregnation results in process sludges and wastewater treatment residues that contain metal arsenates.

The second largest consumption of arsenic oxide is for the production of MSMA, cacodylic acid and similar compounds for use as pesticides. Several production processes are involved and are held proprietary. All of them, however, generate wastewater treatment sludges containing inorganic and organic arsenic compounds. These processes also generate the listed waste K031, which is by-product salts that are contaminated with arsenic compounds. Pesticide formulators using these organoarsenic compounds also generate wastewater treatment sludges, spilled materials, and off-specification formulations containing organoarsenic compounds.

The two veterinary pharmaceutical facilities producing organoarsenic compounds manufacture different products. Each uses proprietary technology. However, both plants can generate the listed wastes K084, K101, and K102, which consist of wastewater treatment sludges, distillation bottoms, and spent carbon, respectively. All these wastes can contain inorganic and organic arsenic compounds.

Production of chemicals from elemental phosphorus is a significant but unrelated source of arsenic-bearing wastes. In producing elemental phosphorus from phosphate rock, arsenic impurities become incorporated as elemental arsenic in the product. One metric ton of phosphorus typically contains about 0.3 kilogram of arsenic. Conversion of the phosphorus to other products such as food grade phosphoric acid, phosphorus trichloride, or phosphorus pentasulfide generates solid and liquid wastes containing either arsenic chlorides or arsenic sulfides. The phosphorous segment of the inorganic chemicals industry generates product purification sludges and distillation bottoms containing arsenic sulfides and arsenic trichloride, respectively.

1.1.4 Processes That Generate Selenium-Containing Wastes

The chief use of selenium is in the electronics industry where it is incorporated in individual electronic components. The selenium is melted and cast into desired shapes, machined, and further processed. Wastes from these operations consist of fines, scrap, and off-specification materials that have a high selenium content. Most of these wastes are reprocessed either onsite or offsite.

The production of cadmium red pigment generates wastewater treatment sludges that contain cadmium, zinc, and selenium. These are generally sold to reclaimers to recover metal values.

Selenic acid is used chiefly as an additive to bright copper and bright chromium electroplating formulations. Thus, selenium may appear as a constituent in wastewater treatment sludges generated by the metal finishing industries.

Other selenium chemicals (selenic acid, etc.) are produced only in small quantities at three facilities. While the Agency does not have

process-specific information on these operations, total production is only a few hundred pounds per year (King 1989). Thus, the amounts of selenium-bearing wastes produced are likely to be small. To help confirm this belief, the Biennial Report found that in 1985, only 765 tons of D010 and 0.001 ton of U204 were generated (USEPA 1987c). No generation is reported for P103, P114, or U205 wastes.

1.2 Waste Characterization

The Agency examined data in the 1986 TSDR Survey, the Generator Survey, EPA reports, and literature sources regarding those facilities that generate and manage wastes containing arsenic and selenium. Characterization data available to the Agency for the arsenic and selenium wastes are summarized below.

1.2.1 Arsenic

The characterization data in Table A-2 located in Appendix A is from the 1986 Generator Survey and is for D004 single streams. Any D004 streams listed in combination with other wastes were not used to characterize D004 wastes because it cannot be determined if the proportion of D004 is so small that the mixed stream is no longer representative of D004 wastes.

The data show D004 wastes divided into eight categories: aqueous inorganic liquids, contaminated soil, inorganic liquids, inorganic sludges, inorganic solids, lab packs, organic liquids, and organic solids. The inorganic liquids category accounts for 85 percent of the D004 wastes, the organic liquids category accounts for 12 percent of the D004 wastes, the inorganic solids category accounts for 2 percent of the D004 wastes, and all the remaining categories are 1 percent of the D004 wastes generated in 1986.

For the purposes of BDAT, wastewaters are defined as wastes containing less than 1 percent TOC and less than 1 percent TSS. All other wastes are defined as nonwastewaters. According to the data, the arsenic concentration in D004 wastewaters ranges from 1 ppb to 1,000 ppm.

For D004 arsenic nonwastewaters, the highest concentrations of arsenic are 75 to 90 percent generated from the "discarding of out of date products or chemicals" and greater than 90 percent for "laboratory wastes." Both of these types of wastes are generated in small volumes (i.e., approximately 30 tons per year). The wood preserving industry generates an inorganic solid from a filtration/centrifuging process that also contains greater than 90 percent arsenic. The volume of this waste stream is unknown. The semiconductor industry generates inorganic nonwastewaters with a total concentration of 10 to 25 percent arsenic, and the chemical products industry generates an organic solid nonwastewater containing 25 to 50 percent arsenic. These D004 wastes discussed above appear to be the most heavily concentrated with arsenic; however, most D004 nonwastewaters appear to contain 1 to 10 percent arsenic.

Table A-3 in Appendix A presents characterization data for K031. This waste, generally a nonwastewater, contains up to 18 percent arsenic and various organic constituents.

Table A-4 summarizes the available characterization data for K084. The data show that K084 wastes are nonwastewaters containing up to 16 percent total organic carbon and up to 25 percent arsenic.

The characterization data for K101 and K102 are located in Table A-5. Waste K101 can contain up to 19 percent 2-nitroaniline and up to 2,000 ppm of arsenic. Waste K102 can contain up to 900 ppm 2-nitrophenol, and up to 8,500 ppm arsenic. Both K101 and K102 are generated nonwastewaters.

The only available data for P and U wastes containing arsenic listing constituents are shown in Table A-6. Characterization data are presented for P010, P011, and P012. Most of these waste sources are described as "laboratory wastes" or "discarding of out-of-date products/chemicals." They are nonwastewaters and can contain up to 50 percent arsenic. The wastes are generated in relatively small volumes (i.e., less than 50 tons).

1.2.2 Selenium

The data in Table A-7 show D010 as wastewater and nonwastewater forms. The wastewaters contain up to 500 ppm of selenium and the nonwastewaters contain up to 25 percent selenium. The table shows that approximately 99 percent of D010 waste generated in 1986 contains 98 percent water and up to 10 ppm selenium and is generated by one generator from the petroleum refining industry. No data are available to characterize any of the P and U wastes containing selenium listing constituents.

1.3 Determination of Waste Treatability Group

EPA believes that wastes with different waste codes produced in similar processes in an industry or in similar industries can be treated, in some cases, to similar concentrations using the same technologies. In these instances, the Agency may combine the codes into a single treatability group.

The arsenic and selenium wastes discussed in this document all contain either arsenic or selenium as the primary hazardous constituent. They are combined into a single treatability group because the arsenic and selenium in wastes generally exhibit positive valence states and have similar chemical behavior. They both show little tendency to exist as solitary cationic species in aqueous solutions and typically exist in

aqueous conditions as oxo-anions (e.g., arsenic appears primarily as anionic arsenite (AsO_3^{-3}) or arsenate (AsO_4^{-3})). This behavior is important, in that selection and performance of treatment technologies for other metals are based primarily on the cationic behavior of the metals in aqueous conditions. Thus, treatment technologies for wastes containing arsenic and selenium are different when compared with wastes containing only other metal constituents.

To further support the selection of just one treatability group, EPA performed a careful review of the generators of the various arsenic- and selenium-bearing wastes and available waste characterization data. Based on this review, the Agency has determined that the nonwastewater forms of wastes D004, D010, K031, K084, K101, K102, P010, P011, P012, P036, P038, P103, P114, U136, U204, and U205, all of which contain arsenic or selenium compounds, have a very limited number of stable nonleachable nonwastewater residuals, and hence require similar types of treatment trains to manage these wastes.

The same analysis applies to wastewater forms of all the arsenic- and selenium-containing wastes, where, again, similar technologies must be employed to remove the arsenic or selenium and which results in stable insoluble arsenic- or selenium-bearing residuals precipitated from the wastewater stream.

2. APPLICABLE AND DEMONSTRATED TREATMENT TECHNOLOGIES

Section 1 established a single treatability group for the management of arsenic and selenium compounds. This section identifies the treatment technologies that are applicable to the treatability group and determines which of the applicable technologies may be considered demonstrated for the purpose of establishing BDAT.

To be applicable, a technology must be theoretically usable to treat the waste in question or to treat a waste that is similar in terms of the parameters that affect treatment selection. [For detailed descriptions of the technologies applicable to these wastes, or for wastes judged to be similar, see EPA's Treatment Technology Background Document (USEPA 1988e) and Appendix B of this document.] To be demonstrated, the technology must be employed in full-scale operation for the treatment of the waste in question or a similar waste. Technologies available only at pilot- and bench-scale operations are not considered in identifying demonstrated technologies.

2.1 Applicable Treatment Technologies

The previous section presents characterization data for the arsenic and selenium wastes of concern. The data show that the wastes can be in wastewater or nonwastewater forms and may or may not contain high levels of organic compounds. The data also show that arsenic can be present in concentrations greater than 90 percent and that selenium may be present at levels as high as 25 percent. The physical and chemical properties for each waste determines which treatment technologies are likely to be applicable. Technologies that are considered applicable for the treatment of organics are those that destroy or remove the organic constituents. For treatment of the arsenic or selenium, those technologies considered applicable are those that stabilize or remove the metals.

Information on treatment of the arsenic and selenium wastes has been obtained from the TSDR Survey, the Generator Survey, literature sources, telephone interviews with generators and treaters of hazardous wastes, and a limited number of site visits.

2.1.1 Nonwastewaters

For the purposes of determining BDAT, nonwastewaters are defined as wastes containing greater than 1 percent total organic carbon (TOC) and/or greater than 1 percent total suspended solids (TSS). There are basically five applicable treatment technologies for arsenic and selenium nonwastewaters; these technologies are described in the following paragraphs.

(1) Incineration. Incineration is an applicable technology for treatment of arsenic and selenium wastes containing organic compounds. The technology converts the organics present in the wastes to carbon dioxide and water. One complication encountered when treating arsenic or selenium wastes is the formation of arsenic trioxide or selenium dioxide, which have low sublimation temperatures (i.e., 193°C and 315°C, respectively) and consequently volatilize as created. For this reason, incinerators treating these wastes should be equipped with air pollution control devices (e.g., wet scrubbers) to remove the arsenic or selenium compounds from the off-gases before these gases may be vented to the atmosphere. Individual types of incinerators are discussed in the Treatment Technology Background Document (USEPA 1988e).

(2) Stabilization. Stabilization processes involve mixing of the waste with stabilizing agents such as asphalts or pozzolanic materials (lime, kiln dust, cement, etc.) and water. The mixture undergoes reaction and sets into a hard solid material. The particles of waste present are thus incorporated into the solid matrix. Stabilization is

discussed in detail in the Treatment Technology Background Document (USEPA 1988e).

(3) Vitrification. Glass vitrification and slag vitrification are high temperature stabilization technologies that are applicable for treatment of arsenic and selenium containing wastes. These technologies are described in more detail in Appendix B.

Glass vitrification is a process wherein the waste is blended at fairly low concentrations (a few percent) into a mixture of lime, soda ash, silica, and other ingredients normally used for glassmaking. The blended waste and glass constituent mixture is then fed to a glassmaking furnace. Material is normally introduced near the top of the furnace and descends to the surface of a pool of molten glass maintained at 1100 to 1200°C. At these temperatures, organic constituents of the waste are combusted, and inorganic constituents dissolve into the glass melt. Molten glass is withdrawn from the base of the furnace and cooled into chunks or blocks. The waste inorganic constituents become physically and chemically incorporated into the glass matrix.

Glass-making furnaces are normally designed so that vapors of more volatile constituents (such as arsenic oxide) condense in the cooler roof sections of the furnace and fall back as solids into the glass melt where they undergo chemical reactions leading to glass formation. Additionally, glassmaking furnaces are normally equipped with air emissions control systems to minimize emissions of volatilized materials. Process vent gases are normally passed through baghouses and wet scrubbers in series to remove entrained particulates and vapors prior to release to the atmosphere. The collected baghouse dusts and scrubber blowdowns can be collected and recycled to the vitrification process.

Slag vitrification technology is very similar to glass vitrification and involves the addition of the arsenic or selenium waste into molten slag using basically the same type of furnace used in glass vitrification. The arsenic or selenium undergo chemical reactions with the molten slag constituents to form complex silico compounds. Cooling of the slag generates a solid mass containing the complex materials in a form that resists leaching of the arsenic and selenium.

(4) Recycle and recovery. Recycle technologies are potentially applicable to most concentrated selenium and arsenic wastes. Recycling technologies for selenium recovery depend on the form of the selenium and can range from simple wet mechanical removal of selenium followed by filtration, to chemical processes that convert the selenium compounds to elemental selenium. During these chemical processes, the waste is treated with an alkaline solution containing an oxidizing agent, such as hydrogen peroxide. The selenium is oxidized, forming a sodium selenite solution. The sodium selenite solution is then filtered. The filtrate (liquid) is then treated with a reducing agent (sulfur dioxide). Elemental selenium precipitates, is recovered by filtration, and then is washed, dried, and reused (Elkin 1978).

In theory, arsenic oxide could be recovered as a result of the use of incineration processes. Since the arsenic oxide has a low sublimation temperature (193°C), it could be recovered as it volatilizes. However, arsenic, unlike selenium, is not as valuable a commodity, and thus there is little economic incentive to attempt to recycle arsenic-bearing waste.

(5) Chemical precipitation. Chemical precipitation, although applicable to some nonwastewaters, is generally conducted in aqueous solutions and is primarily utilized to treat wastewaters. Hence, the technology is discussed in the wastewater section.

2.1.2 Wastewaters

For the purposes of determining BDAT, the Agency defines wastewaters as wastes containing less than 1 percent total organic carbon (TOC) and less than 1 percent total suspended solids (TSS). Chemical precipitation, ion exchange, and carbon adsorption technologies are applicable for treating selenium and arsenic wastewaters. These technologies are discussed separately in the following sections.

(1) Chemical precipitation. Chemical precipitation is a technology that removes dissolved metals from solution. The choice of precipitating agent used is generally dictated by the cost of chemicals and process conditions. However, consideration should also be given to the stability of the nonwastewater residual (i.e., precipitate) before choosing the precipitating agent. Stability results for several precipitates are discussed in Section 3. Lime, manganese, ferric, and sulfide precipitation are all applicable precipitating agents for treatment of arsenic wastewaters. Hydroxide precipitation of arsenic cannot be achieved at any pH. Arsenic precipitation occurs only at very high pH (i.e., 12) when lime is used to form calcium arsenate (Bhattacharyya 1981). When manganese sulfate is added, manganese arsenate is precipitated from solution.

Sulfide is applicable for treatment of arsenic in the form of arsenates but relatively ineffective for arsenites at pH 7 (Patterson 1985). Normally, sulfide precipitation is conducted under neutral or alkaline conditions to precipitate most metals. However, the sulfides of arsenic (As_2S_3 and As_2S_5) are insoluble in an acid media, but they become rapidly soluble at pH levels above 8. Consequently, this process requires the precipitation to be conducted under highly acidic conditions. The wastewater must first be acidified to a pH of 3.9 or less. Hydrogen sulfide is then added to the solution or slurry. Arsenic

sulfides precipitate and are collected by filtration; the wastewater or slurry can then be treated for sulfide removal and neutralization.

Another chemical precipitation process for treatment of arsenic wastewaters is ferric precipitation and ferric coprecipitation. Generally, ferric coprecipitation of arsenic requires the use of at least a fivefold excess of ferric salt above the stoichiometric amount that would be required for ferric precipitation. During the coprecipitation process, the wastewater is first mixed with a solution of a ferric salt (e.g., ferric chloride or ferric sulfate). The pH is adjusted to about 5.0. A ferric hydroxide floc will precipitate; this floc will also contain some solid ferric arsenate. After the initial precipitation, the pH is raised to about 8.0 by the addition of alkaline agents such as lime, soda ash, or caustic. The residual ferric salts in the solution then precipitate as ferric hydroxide. The solids (ferric arsenate and ferric hydroxide) are then removed from the solution by clarification and filtration.

Ferric coprecipitation appears to be effective for arsenic in the form of arsenate salts or for arsenic forms that can be converted to inorganic arsenate salts. Therefore, before the process is used, all arsenic forms should be converted to the pentavalent (arsenate) state. Chemical oxidation will convert trivalent arsenic (arsenite) and other lower valence state arsenic compounds into arsenates. Several types of oxidants, such as hydrogen peroxide, alkaline permanganate solutions, and solutions of sodium hypochlorite, are potentially useful for these purposes.

Selenium may be contained in several chemical forms in wastes. Elemental selenium can be removed with filtration or settling since it is insoluble in water. Oxidized forms of selenium (selenium dioxide, seleneous and selenic acids, and their salts) are generally soluble in water, but can be precipitated as elemental selenium by reducing the

oxidized forms with a reducing agent such as sulfur dioxide. Iron coprecipitation is capable of above 80 percent selenium removal, with the efficiency increasing with decreasing pH (Patterson 1985). This process is similar with respect to operating conditions of the sulfite or sulfur dioxide process for reduction of chromates discussed in the Treatment Technology Background Document (USEPA 1988e).

(2) Ion exchange. In the ion exchange process, wastewater containing low levels of ionic selenium (e.g., selenides, selenates, or selenites) or ionic arsenic wastes (e.g., arsenites, arsenates, or organoarsenic acids) is passed through an anionic exchange resin bed. Negatively charged selenium ions or arsenic ions replace chloride or other negative ions in the bed and are thus removed from the solution. The resultant wastewater is then either discharged or subjected to additional treatment. Periodically, the resin column is removed from service and regenerated. The regeneration process generates a concentrated solution containing selenium or arsenic compounds, which requires additional treatment. Ion exchange is described in greater detail in the Treatment Technology Background Document (USEPA 1988e).

(3) Carbon adsorption. Carbon adsorption may also be used to remove low levels of dissolved selenium or arsenic compounds from wastewaters. Unlike ion exchange, this process is also applicable to nonionic compounds containing selenium or arsenic. Here, the wastewater is passed through a bed of activated carbon. Selenium or arsenic compound molecules or ions adsorb onto the carbon particles and thus are removed from the solution. The treated wastewater may then either be discharged or further treated to remove other toxic species. Periodically, the carbon adsorption columns are removed from service and the spent carbon is replaced. The spent carbon is normally regenerated by thermal processes. When selenium or arsenic wastes are regenerated, a release of volatile arsenic or selenium compounds could result; thus, an air emissions control system should be employed. Carbon adsorption is

discussed in greater detail in the Treatment Technology Background Document (USEPA 1988e).

2.2 Demonstrated Technologies

The information in the following paragraphs has been gathered by review of the 1986 TSDR Survey, the Generator Survey, data submitted to the Agency, and data in literature sources. The sources are listed in the reference section and can be found in the Administrative Record for this background document.

2.2.1 Demonstrated Technologies for Nonwastewaters

At present, the most widely used method of disposal for arsenic nonwastewaters is landfilling at hazardous waste landfills. Currently, most nonwastewaters containing high concentrations of selenium are reprocessed onsite or offsite to recover metal values.

(1) Incineration The Agency believes that incineration is demonstrated to treat organic wastes containing arsenic or selenium because the Agency has identified at least one facility incinerating arsenic wastes and one facility incinerating selenium wastes. Generally, incineration is used to treat low-level arsenic and selenium wastes. Incineration of high-level (i.e., greater than 1 percent) arsenic-bearing or selenium-bearing wastes is not commonly practiced because of the need for special air emission control systems on incinerators. However, most commercial incineration facilities have the capabilities of blending high-level arsenic wastes with other wastes to meet their Btu, chlorine, metal emissions, particulate emissions, and other requirements.

EPA believes that the technology to remove high concentrations of arsenic or selenium from incineration off-gases is demonstrated because smelters are currently removing such concentrations from flue gases.

Copper smelters that process ores containing arsenic and sulfur, and that produce sulfuric acid from the sulfur dioxide rich smelter flue gases generally cool the flue gases to below 120°C. At this temperature, arsenic oxide condenses as a solid dust. The arsenic oxide dust is collected in baghouses, and the gases are further cleaned by wet scrubbing prior to use in sulfuric acid production. The baghouse and the scrubber blowdown contain arsenic oxide. Presently, commercial waste treatment incinerators are not equipped with this type of two-stage vent gas treatment system, but could be so equipped in the future to effectively remove volatile metals from off-gases.

(2) **Stabilization**. Stabilization is demonstrated to treat both arsenic and selenium wastes because the Agency has identified several facilities treating such wastes. The Agency knows of at least one facility using cement or cement silicate to stabilize D004 wastes. Additionally, the Agency has identified another facility using a proprietary stabilization process for treatment of arsenic wastes.

(3) **Vitrification**. EPA has identified one facility performing pilot-scale vitrification tests on slags containing up to 24 percent arsenic. The Agency believes this to be a similar matrix to arsenic wastes of concern based on the high arsenic concentration. Full-scale vitrification processes have been used to treat radioactive wastes and other hazardous wastes containing metals and arsenic. Because of the extreme hazards of radiation and the precautions required (e.g., extensive air monitoring) when treating radioactive wastes, the Agency believes that these wastes are more difficult to treat than arsenic-wastes. Consquently, EPA believes that vitrification is demonstrated to treat arsenic wastes. Because of the similarities in chemical behavior between arsenic and selenium, EPA believes that vitrification is also demonstrated to treat selenium wastes.

In addition, commercial plate glass typically contains about 0.3 percent arsenic. Arsenic oxide has been used for years as a fining agent to remove tiny, dispersed air bubbles and also as a decolorant for glass. Selenium has also been used as an additive to glass at concentrations less than 0.3 percent to impart a red coloration to the glass. In the normal glassmaking process, the arsenic and/or selenium are blended with the other constituents prior to introduction into the glass furnace. Glass furnaces are designed to minimize any arsenic or selenium emissions. EPA believes that some glass formulations may be similar to some arsenic and selenium nonwastewaters with regard to either the arsenic or selenium concentrations. The Agency also believes that the vitrification treatment technology is essentially the same as that used in glass manufacturing.

(4) **Recycle/Recovery**. Recycle/recovery is not currently demonstrated for treatment of arsenic-bearing nonwastewaters. The Agency is aware of a copper smelter in Canada that is reviewing the idea of accepting wastes generated by the wood preserving industry, processing the waste materials in the smelter, and recovering arsenic trioxide from the flue gases. The recovered arsenic trioxide would then be sold to produce the arsenic acid used in the production of wood preservatives. Furthermore, the Agency has identified one producer of wood preservatives using arsenic-bearing lead smelter flue dusts containing about 50 percent arsenic to produce arsenic acid.

Selenium is generally recovered from "anode slimes" containing approximately 15 percent selenium. Anode slimes refer to the residual material collected from the bottom of the electrolytic cells during the refining of copper. Conventional anode slime treatment processes usually remove copper first, then recover precious metals in the form of an alloy. Selenium is considered an impurity and is collected as a by-product. While the recovering of copper, gold, and silver are about 97 percent, recovery of selenium seldom exceeds 80 percent. Selenium

tends to oxidize and volatilize at fairly low temperatures; consequently, its evolution during all heat treatment steps distributes this element over much of the process. In the selenium recovery step, sulfur dioxide and sulfuric acid are added to the selenium slurry. Elemental selenium precipitates and is recovered by filtration (Osseo-Asare 1982).

Because the economic incentive is greater, most of the elemental selenium present at high concentrations in waste from the photocopying and electronics industries is currently recycled. Scrap xerographic materials containing selenium have been exported to Canada and the United Kingdom for processing to recover selenium. An estimated 200 tons of selenium metal refined from scrap was imported in 1987. Hence, the Agency believes recovery to be demonstrated for selenium nonwastewaters.

2.2.2 Demonstrated Technologies for Wastewaters

(1) Chemical precipitation. Chemical precipitation has been demonstrated for wastewaters containing up to 1,700 ppm arsenic by the veterinary pharmaceuticals segment of the arsenic chemicals industry at a facility in Charles City, Iowa (USEPA 1987b). The facility uses a three-stage precipitation system in which most of the arsenic is removed from wastewaters as calcium and manganese arsenates. Precipitation with excess iron salts to form a precipitate containing ferric oxides and ferric arsenate is used as the final treatment step. Hence, the Agency believes precipitation to be demonstrated to treat arsenic wastewaters.

Much of the work involving ferric precipitation has been done by the mining industry to develop methods for treatment of arsenic-bearing residuals generated by the mining and smelting of arsenic-bearing ores. The one-stage process of using ferric precipitation alone to remove arsenic from wastewaters is currently in full-scale use at two Canadian gold mining operations and hence is demonstrated to treat wastewaters containing arsenic.

The sulfide precipitation of arsenic is used for wastewater and product treatment in the phosphorous chemicals segment of the inorganic chemicals industry and hence is demonstrated to treat wastewaters containing arsenic.

Chemical precipitation to reduce soluble selenates and selenites to insoluble elemental selenium is an integral part of the process for the manufacture of selenium from copper refinery by-products (Elkin 1979). The Agency believes the aqueous selenium-containing solution generated by copper refineries to be more difficult to treat than the selenium wastewaters because the selenium concentration is expected to be greater in the copper refineries aqueous solutions (i.e., approximately 50,000 mg/l) than in wastewaters (Osseo-Asare 1982). Additionally, the Agency knows of one facility using ferrous ions to precipitate selenium from wastewaters. Therefore, chemical precipitation is demonstrated to treat selenium wastewaters.

(2) Ion exchange. The Agency has identified at least one facility using ion exchange to treat D004 wastewaters and therefore believes that ion exchange is demonstrated to treat arsenic-bearing wastewaters. Because of the similarity in chemical properties between arsenic and selenium, the Agency believes that ion exchange is also demonstrated for selenium.

(3) Carbon absorption. The Agency has identified at least one facility using carbon absorption to treat D004 wastewaters and consequently believes that it is demonstrated to treat arsenic-bearing wastewaters. Because of the similarity in chemical properties between arsenic and selenium, the Agency believes that carbon absorption is also therefore, demonstrated for selenium.

3. PERFORMANCE DATA BASE

This section presents the data available to EPA on the performance of demonstrated technologies in treating the listed wastes. These data are used elsewhere in this document for determining which technologies represent BDAT (Section 4), for selecting constituents to be regulated (Section 5), and for developing treatment standards (Section 6). Eligible data, in addition to full-scale demonstration data, may include data developed at research facilities or obtained through other applications at less than full-scale operation, as long as the technology is demonstrated in full-scale operation for a similar waste or wastes as defined in Section 2.

Performance data, to the extent that they are available to EPA, include the untreated and treated waste concentrations for a given constituent, values of operating parameters for the treatment technology that were measured at the time the waste was being treated, the values of relevant design parameters for the treatment technology, and data on waste characteristics that affect performance of the treatment technology.

Where data are not available on the treatment of the specific wastes of concern, the Agency may elect to transfer data on the treatment of a similar waste or wastes, using a demonstrated technology. To transfer data from another waste category, EPA must find that the wastes covered by this background document are no more difficult to treat (based on the waste characteristics that affect performance of the demonstrated treatment technology) than the treated wastes from which performance data are being transferred.

3.1 Performance Data Base for Nonwastewaters

The Agency reviewed data from literature sources, data generated from EPA treatment testing, and data submitted to the Agency by industry to

develop the treatment performance data base for arsenic and selenium wastes. Some of the industry data was submitted as confidential business information (CBI). This information could not be presented in this document, but it is contained in the RCRA CBI docket at EPA. The performance data presented in the CBI submittals are consistent with the data findings described in this section.

3.1.1 Incineration Performance Data

Performance data collected by EPA for rotary kiln incineration of both K101 and K102 are not presented in this document, but can be found in the best demonstrated available technology (BDAT) background document for K101 and K102 low arsenic subcategory (USEPA 1988d). The data present the analytical results for samples collected during the Agency's sampling visit at a pilot-scale incineration facility. The results include analytical data for the untreated K101 and K102 wastes, the treated K101 and K012 wastes (kiln ash), and the scrubber wastewater.

Performance data for K101 consist of four sample sets of treated and untreated data. The untreated data show arsenic ranging from 590 to 1950 ppm and 2-nitroaniline in concentrations up to 191,000 ppm. The scrubber water data show arsenic ranging from 91.7 to 504 mg/l and 2-nitroaniline less than the detection limit of 0.05 mg/l. The ash data show arsenic ranging from 244 to 360 ppm total concentration and 0.656 to 0.73 in the TCLP leachate. The concentration of 2-nitroaniline is less than the detection limit of 2.0 mg/kg in the ash residual. The operating temperature of the kiln ranged from 1625 to 1960°F and the afterburner ranged from 1868 to 2019°F.

The performance data for K102 consist of six sample sets of treated and untreated data. The untreated data show arsenic ranging from 3,060 to 8,320 ppm and 2-nitrophenol ranging from 220 to 870 ppm. The scrubber water data show arsenic ranging from 341 to 713 mg/l and 2-nitrophenol

less than the detection limit of 0.010 mg/l. The ash data show arsenic ranging from 633 to 1,080 ppm total concentration and 8.69 to 38.3 mg/l in the TCLP leachate. The concentration of 2-nitrophenol is less than the detection limit of 1.0 mg/kg in the ash residual. The operating temperatures of the kiln ranged from 1750 to 2000°F and the afterburner ranged from 1868 to 2019°F.

3.1.2 Stabilization Performance Data

The Agency has bench-scale stabilization test results for nine different stabilizing processes. These data are shown in Table C-1 located in Appendix C. Each stabilizing process was performed with three different waste types (i.e., K031, arsenic sulfide waste, smelter dust). The data show that before stabilization, the K031 has an arsenic concentration of 533 mg/l in the EP-toxicity leachate, the arsenic sulfide has an arsenic concentration of 41 mg/l in the EP-toxicity leachate, and the smelter dust has an arsenic concentration of 6,450 mg/l in the EP-toxicity leachate.

For the K031 waste, all nine processes show reductions of arsenic present in the EP-toxicity leachate, with the asphalt encapsulation process achieving the lowest value. For the arsenic sulfide waste, the leachate results after using cement stabilization, silicate polymer fixation, clay stabilization, silicate fixation, and polyethylene encapsulation show an increase of arsenic in the leachate. The urea formaldehyde resin encapsulation process achieves the lowest arsenic concentrations in the EP-toxicity leachate. In one instance, the smelter dust shows an increase of arsenic in the EP-toxicity leachate using cement stabilization. The silicate polymer fixation process achieves the lowest value of arsenic in the EP-toxicity leachate for the smelter dust.

The Agency also has data on efforts made to stabilize K031 waste containing organoarsenic compounds. These data are shown in Table C-2 located in Appendix C. These data consist of total concentration and the TCLP leachate results for BDAT list metals present in the untreated waste. The untreated waste stabilized with three different binders: cement, lime/fly ash, and kiln dust. Three separate sample results are presented for each stabilization binder. In one instance, stabilization of the waste with cement resulted in an increase in arsenic leachability.

EPA has stabilization performance data for waste soils containing arsenic. The waste was stabilized using a mixture of pozzolan, portland cement, and a proprietary material called Superset. The data in Table C-3 show the results of two different mixture combinations. Mix A contains 31.4 percent waste soil, 2.1 percent Superset, 28.6 percent pozzolan, 28.6 percent portland cement, and 9.3 percent water. The data for Mix A show arsenic present in the untreated EP-toxicity leachate at 268 mg/l and 21.2 mg/l in the treated leachate. Mix Z contains 52.7 percent waste soil, 1.0 percent Superset, 18.8 percent pozzolan, 8.0 percent portland cement, and 18.5 percent water. The data for Mix Z show arsenic present in the untreated EP-toxicity leachate at 268 mg/l and 13.0 mg/l in the treated leachate.

In some instances, the stabilization process may simultaneously occur as a result of the chemical precipitation process. The Agency also has information on the stability of ferric arsenate precipitates prepared under different conditions. These data are shown in Table C-4 in Appendix C. Three different ferric-to-arsenic weight ratios were subjected to pH values ranging from 3.0 to 9.0. In all three cases, the data show that while ferric arsenate is fairly insoluble at low pH values, its solubility increases at higher pH levels.

The Agency also has data on EP-toxicity test results for precipitates of lime neutralization sludges, where lime addition is the only treatment used to remove arsenic and selenium from wastewaters. Twenty-one sludge samples were subjected to the EP-toxicity test. The arsenic contents of the samples ranged from 1,900 to 6,900 mg/kg, and 11 failed the test of 5.0 mg/l in the EP-toxicity leachate for arsenic. The selenium ranged from 10 to 329 mg/kg, and eight failed the test of 1.0 mg/l in the EP-toxicity leachate for selenium. These data are shown in Table C-5 in Appendix C and were obtained from copper smelter treating wastewaters containing inorganic arsenic and selenium compounds.

The data in Table C-6 present the TCLP leachate results of three wastewater treatment precipitates generated as a result of treating D004 wastewaters with three different precipitating agents (i.e., ferric sulfate, calcium hydroxide, and manganese sulfate). The wastewater performance data are present in Table C-9. The ferric arsenate precipitate has an arsenic total concentration of 9,760 mg/kg and a TCLP leachate of 0.508 mg/l; the calcium arsenate precipitate has an arsenic total concentration of 45,200 mg/kg and a TCLP leachate of 2,200 mg/l; and the manganese arsenate precipitate has an arsenic total concentration of 47,400 mg/kg and a TCLP leachate of 984 mg/l.

3.1.3 Vitrification Performance Data

The Agency has data on the slag vitrification of arsenic. Arsenic oxide (As_2O_3) in flue dust was converted to calcium arsenate ($Ca_3(AsO_4)_2$) by low temperature (i.e., 400°C) roasting of mixtures of the dust and pelletized lime in the air. The resulting calcined mixture was dissolved in molten iron silicate slag at temperatures up to 1290°C without volatilization of arsenic oxides. The dissolution process is accomplished by adding the roasted flue dust to molten slag immediately after tapping the slag. These results show that arsenic oxide, if converted to a

nonvolatile arsenic salt, can be successfully vitrified in slag. The data are presented in Table C-7 located in Appendix C. These data consist of 14 separate data points, with arsenic concentration in the slag ranging from 0.3 to 23.5 percent and the EP-toxicity leachate containing 0.007 to 1.8 mg/l (Twidwell 1985).

The Agency also has data on the EP-toxicity testing of glass samples prepared by the vitrification of waste in a furnace in which arsenic and other EP-toxic metals were incorporated into the formulation used to produce the glass. This information, provided in Table C-8 in Appendix C, shows that the metals have low solubilities in the glass matrix. These data consist of five different samples that were obtained from evaluation of the glass vitrification process. The data are for leachate results using the EP-toxicity test.

EPA has data for the *in situ* vitrification of a waste contaminated with arsenic and organochlorine pesticides. The data show arsenic concentrations up to 4.4 percent in the untreated waste. The treatment process achieves a 99.99 percent destruction removal efficiency for the organics, and the glass produced has 0.91 mg/l arsenic in the TCLP leachate. The vitrification process operated at temperatures of approximately 1200°C. The system used has air pollution control equipment to remove any arsenic that volatilizes during treatment (Timmons 1989).

3.2 Performance Data Base for Wastewaters

3.2.1 Chemical Precipitation Performance Data

The Agency performed an onsite sampling and analysis test at a facility in Charles City, Iowa, to help develop treatment standards for arsenic present in wastewaters. The wastewater treatment process at the site consisted of a three-stage chemical precipitation process whereby

calcium arsenate was precipitated in the first stage, manganese arsenate was precipitated in the second stage, and ferric arsenate was precipitated in the third stage. The data consist of five sample sets of untreated and treated results for each stage of the chemical precipitation process. The incoming raw wastewater generally contained concentrations up to 1,700 mg/l of arsenic. Five samples taken of the effluent from the ferric treatment process revealed arsenic values ranging from 0.163 to 0.580 mg/l arsenic. These data are presented in Table C-9 in Appendix C. Data for the precipitates are shown in Table C-6.

The data in Table C-10 show the correlation between the molar ratio of iron to arsenic and the treatment performance of the ferric arsenate precipitation process for arsenic removal. The data show that as the amount of the ferric precipitating agent, in this case ferric sulfate, is increased, more arsenic can be removed from the wastewaters.

The Agency has data on the use of the ferrous ion to reduce low levels of selenate ion to selenium in wastewaters. These data consist of five sample sets of untreated and treated results. The data are shown in Table C-11, also in Appendix C.

4. IDENTIFICATION OF BEST DEMONSTRATED AVAILABLE TECHNOLOGY (BDAT)

This section presents the Agency's rationale for determining best demonstrated available technology (BDAT) for the various arsenic- and selenium-containing hazardous wastes. To determine BDAT, the Agency examines all available performance data on technologies that are identified as demonstrated to determine whether one or more of the technologies performs significantly better than the others. The technology that performs best on a particular waste or waste treatability groups is then evaluated to determine whether it is "available." To be available, a technology must (1) be commercially available to any generator and (2) provide "substantial" treatment of the waste, as determined by evaluation of analytical accuracy-adjusted data. In determining whether a treatment is substantial, EPA may consider data on the performance of a waste similar to the waste in question provided that the similar waste is at least as difficult to treat.

4.1 Nonwastewaters

Consistent with EPA's methodology for determining BDAT as summarized above, the Agency evaluated all the information and performance data to determine the "best" performing technology. The demonstrated technologies for arsenic and selenium nonwastewaters are incineration, stabilization, and vitrification. Additionally, recycle/recovery is demonstrated for selenium nonwastewaters.

The Agency examined the performance data for incineration, but concluded that incineration is not "best" because it is only demonstrated for low level arsenic wastes. Furthermore, incineration only destroys any organic contaminants, but not arsenic or selenium. The arsenic and selenium in ash or scrubber water are likely to require additional treatment.

Next, the Agency reviewed the stabilization data and determined that stabilization is not considered "best." EPA made this determination because the performance data appear inconsistent from waste to waste, possibly because the arsenite, and arsenate salts of common metals generally have relatively high solubilities in water under alkaline conditions. For example, arsenic pentasulfide and ferric arsenate are fairly insoluble in acidic or neutral aqueous solutions. However, both solubilities increases substantially at pH values above 9.0; hence, stabilization with alkaline materials such as lime and cement is undesirable. As a result, binders such as plastics may prove useful, but the Agency has no data to substantiate this belief.

The Agency also examined the stability of arsenic compound precipitates and concluded that the ferric arsenate coprecipitate is the most stable, but still leaches and may require further treatment. It should be mentioned that when using ferric coprecipitation, sludge volume generated is generally larger than when using other precipitates. Other arsenates, such as calcium arsenate, have also been examined by the Agency as alternatives. However, these materials all have significantly higher solubilities than does ferric arsenate. Furthermore, some of these salts react with carbon dioxide in the air to form calcium carbonate and soluble arsenic compounds (Robins 1981).

The Agency considered the use of monofill (i.e., a hazardous waste landfill exclusively devoted to one type of waste) to achieve conditions desirable for disposal of arsenic wastes and/or selenium wastes. Such a monofill facility would accept, for instance, only ferric arsenate containing wastes and no other hazardous wastes. The landfill leachate pH would have to be monitored to ensure that it does not become excessively alkaline, and monofill treatment with acidic solutions might be required to correct any developing alkalinity problem. No such monofill operations currently exist for the commercial management of

arsenic or selenium wastes. As a result, the Agency regards the monofill approach as possible but not available.

The vitrification process is capable of managing a wide variety of arsenic- and selenium-bearing wastes. At the temperatures at which the vitrification process is normally operable (1100 to 1400°C), organoarsenic compounds and organic selenium compounds will be combusted to arsenic oxide or selenium dioxide, carbon dioxide, and water. The arsenic oxide and selenium dioxide formed will react with the other glass-forming constituents and become immobilized in the glass formed. Inorganic compounds alone or inorganic compounds mixed with organic materials can likewise be vitrified.

Based on the above analysis, glass or slag vitrification is considered the "best" technology. Furthermore, treatment of arsenic using vitrification is substantial. It has been shown that arsenic can be vitrified into slag at concentrations of up to 24 percent arsenic and that the slag so generated will pass the EP-toxicity test for arsenic.

The Agency has identified one commercial waste vitrification facility and has determined that the vitrification process units are currently available for purchase. Consequently, EPA believes vitrification is available.

The Agency believes that treatment using vitrification achieves reductions of hazardous constituents that are substantial and it is commercially available; therefore, vitrification represents BDAT for arsenic nonwastewaters. Since selenium has chemical properties very similar to arsenic, the Agency believes that vitrification is also BDAT for selenium nonwastewaters.

According to information available to the Agency, most nonwastewater forms of selenium-containing wastes that have high concentrations of selenium are currently reprocessed. However, the various recycle/recovery technologies may not be viable for generators of wastes containing fairly low concentrations of selenium compounds. For this reason, recycle/recovery is not being considered as BDAT for selenium by the Agency. Nevertheless, recycle and reuse is encouraged where viable.

4.2 Wastewaters

EPA has identified chemical precipitation, ion exchange and carbon absorption as demonstrated to treat arsenic and selenium wastewaters. However, chemical precipitation is the only demonstrated technology for which the Agency has data. The Agency has no reason to believe that ion exchange or carbon absorption could improve the level of performance; therefore, chemical precipitation is the "best" performing technology for wastewater forms of arsenic- and selenium-bearing wastes. Data available to the Agency indicate that the iron arsenate precipitation alone or in combination with other precipitation methods is capable of removing arsenic from wastewaters down to well below the characteristic concentration levels (5 mg/l). Additionally, wastewater forms of selenium-containing wastes can be reduced to precipitate elemental selenium or can be precipitated with ferrous ion.

The Agency determination of substantial treatment is based on reductions of arsenic from 1,670 mg/l in the untreated wastewaters to 0.224 mg/l in the treated wastewaters. EPA believes that the reductions of hazardous constituents are substantial and that chemical precipitation is available to treat arsenic and selenium wastewaters because it is commercially available; therefore, chemical precipitation represents BDAT for arsenic and selenium wastewaters.

5. SELECTION OF REGULATED CONSTITUENTS

For the characteristic wastes (i.e., D004 and D010), the Agency cannot accurately determine all constituents that may be present in every waste. All D004 wastes contain arsenic and all D010 wastes contain selenium, but the wastes are diverse with respect to other constituents that may be present, such as organics and cyanide. Therefore, the Agency has determined that D004 will be regulated for arsenic and D010 will be regulated for selenium.

The K101 and K102 (low arsenic subcategory) nonwastewater treatment standards for a number of metal and organic constituents were promulgated as part of the First Third regulations in August 1988. The BDAT for the development of the original performance standards was incineration. Arsenic standards were not established at that time because EPA could not determine BDAT for the arsenic present in K101 and K102. The Agency is proposing to develop an arsenic performance standard based on the performance of vitrification for the nonwastewater forms of K101 and K102. Because the vitrification process operates at temperatures of approximately 2300°F and the incineration process used to treat K101 and K102 wastes operated at temperatures of less than 2000°F, vitrification should result in destruction of the organics present in the waste. For this reason, the Agency feels that regulation of the same organic constituents that were selected for regulation in August 1988 is still valid. Other metal constituents present in the wastes will be incorporated into the slag or glass matrix along with the arsenic. Consequently, the Agency believes the other metals present in the K101 and K102 wastes will be controlled by the regulation of arsenic.

The wastes designated by codes K031 and K084 were originally listed by the Agency because of their arsenic content; however, the K031 and K084 wastes also may contain some organic compounds. The Agency has no

performance data for the thermal destruction of organics present in K031 and K084 wastes, but believes that the organics present will be combusted at the operating temperatures of the vitrification processes. Any ash generated will be incorporated into the glass or slag matrix, along with the arsenic present. As a result, the Agency feels that regulation of the arsenic alone is sufficient to ensure proper treatment of other constituents that may be present in K031 and K084.

For all of the P and U constituents, methods to analyze the listed compounds in treatment residuals are not currently available. Although the Agency recognizes that these compounds exist, and that the manufacturers may have methods to verify their purity and determine their product specifications, there are no EPA-approved analytical procedures to ascertain trace quantities of these chemicals in the raw sample or in the residues from treatment. Consequently, EPA will use arsenic as a surrogate for arsenic acid (P010), arsenic trioxide (P011), arsenic pentoxide (P012), dichlorophenyl arsine (P036), diethyl arsine (P038), and cacodylic acid (U136). The Agency will use selenium for a surrogate for selenourea (P103), thallium selenite (P114), selenium dioxide (U204), and selenium disulfide (U205). Thallium selenite (P114) is also regulated for thallium. The development of the thallium standard is discussed in the Best Demonstrated Available Technology (BDAT) for P and U Thallium Wastes (USEPA 1989c).

6. CALCULATION OF BDAT TREATMENT STANDARDS

In this section, the performance levels of the best technologies for treatment of the arsenic and selenium wastes are calculated. For nonwastewaters, this calculation is based on the treatment data presented in Table C-7 for vitrification. For wastewater, this calculation is based on the treatment data in Table C-9 for chemical precipitation. For a more detailed description of how the Agency calculates treatment standards, refer to Methodology for Developing BDAT Treatment Standards (USEPA 1988c). Appendix D presents the analytical methods and quality assurance/quality control (QA/QC) data used to calculate the treatment performance standards.

6.1 Arsenic Nonwastewaters

The Agency has no data representing TCLP leachate concentrations from residuals using vitrification specifically for any of the arsenic RCRA characteristic or listed wastes. EPA has performance data for vitrification of an arsenic-containing slag. These data consist of 14 data points, with one data point showing that an arsenic concentration of 23.5 percent in the vitrified slag leachates at 1.8 mg/l based on the EP-toxicity test. EPA would expect the same level of performance to be achieved in the residuals from vitrification of D004, K031, K084, K101, K102, P010, P011, P012, P036, P038, and U136 because for most of these wastes, the untreated arsenic concentrations are less than 23.5 percent. In addition, the Agency believes that the organic and organometallic bonds present in some of these wastes will be destroyed by the high temperature at which the vitrification processes operate.

6.1.1 D004, K031, K084, P010, P011, P012, P036, P038, and U136 Nonwastewaters

The BDAT treatment standard representing the EP leachate concentration in D004, K031, K084, P010, P011, P012, P036, P038, and U136 nonwastewaters

was determined by adjusting the 1.8 mg/l from Table C-7 for accuracy using a percent recovery of 90 percent and multiplying the corrected value of 2.0 by a variability factor of 2.8 (USEPA 1988c). It should be mentioned that these data have no QA/QC results available, so recovery values were transferred from a similar matrix (i.e., the TCLP leachate from the K102 ash generated during incineration treatment). The calculation of the treatment standard is shown in Table 6-1 at the end of this section.

The Agency is aware the some arsenic wastes are generated at concentrations greater than 90 percent total arsenic. To treat these wastes, the Agency believes that more glass-forming reagents can be added to the molten slag/waste mixture, and the same treatment performance could be achieved by the vitrification process.

6.1.2 K101 and K102 Nonwastewaters

The Agency is proposing to change the nonwastewater standards for K101 and K102 promulgated on August 17, 1988, by eliminating the low and high level arsenic subcategories and by establishing a concentration-based treatment standard for arsenic of 5.6 mg/l in the EP leachate. This standard is based on the performance of vitrification.

The organics performance standards based on the detection limits will not change. The Agency believes that the organic constituents present in these wastes would be destroyed to nondetectable levels by the high temperatures at which vitrification processes operate (temperatures comparable to incineration).

6.2 Arsenic Wastewaters

The Agency has data on precipitation of arsenic using lime followed by manganese and ferric sulfate in a three-stage alkaline process, from

wastewaters identified as D004 by the veterinary pharmaceutical industry. The Agency believes that these data represent a matrix that is very difficult to treat, since it consists of a mixture of organic and inorganic compounds, including organoarsenicals and inorganic arsenic compounds in concentrations up to 1,600 ppm. According to these data, concentrations of arsenic in the treated wastewaters are as low as 0.16 mg/l.

Some arsenic and selenium wastewaters, such as those from wood preserving operations, may require more extensive treatment trains in order to treat hexavalent chromium, other metals, and organics which could possibly interfere with the treatment of the arsenic or selenium. A reduction step for hexavalent chromium and an oxidation step (with reagents such as hydrogen peroxide or hypochlorite) may be necessary to treat the organics. In addition, complexed organometallics which may be present will probably have to be oxidized or otherwise removed prior to conversion of the metals to their proper valence state for further metal treatment by precipitation. However, the Agency currently lacks data that indicate that pretreatment steps such as hexavalent chromium reduction and chemical oxidation of organics can not remove these potential interferences. This is further supported by the fact that quantitative analytical methods for arsenic and selenium in waste samples include such pretreatment steps to remove the interferences during analysis.

6.2.1 D004, K031, K084, P010, P011, P012, P036, P038, and U136 Wastewaters

The Agency is proposing a D004 wastewater treatment standard of 0.79 mg/l for total arsenic concentration. The calculation of the treatment standard is shown in Table 6-1 using the accuracy corrected data. EPA believes that the data collected for D004 wastewaters represent data on a waste that is more difficult to treat than wastewater forms of K031, K084, P010, P011, and P012. These wastes are typically

generated as nonwastewaters. Therefore, wastewater forms of these wastes are expected to be generated from accidental spills, leachate collection, or the treatment process itself. It is expected that these untreated K, U, and P wastewaters generally will be more dilute than the untreated D004 wastewaters tested by the Agency. Further, while K031, K084, P035, P038, and U136 wastes all contain organic forms of arsenic, the Agency believes that they could be chemically oxidized (using peroxides, permanagates, persulfates, or perchlorates) to destroy the organometallic bond prior to precipitation.

Based on the performance data precipitation data for D004 wastewaters, the Agency is proposing a concentration-based treatment standard of 0.79 mg/l for arsenic contained in K031, K084, P010, P011, P012, P036, P038, and U136 wastewaters. The Agency is proposing to transfer the D004 performance data and concentration-based treatment standard of 0.79 mg/l for K031, K084, P010, P011, P012, P036, P038, and U136 wastewaters. This is a reasonable approach given that: (1) the D004 wastewater that was tested by the Agency contained organo-arsenicals similar in structure to those contained in K031, K084, P036, P038, and U136; (2) the D004 wastewater also contained inorganic arsenic compounds similar to those contained in K031, K084, P010, P011, and P012; (3) the untreated wastewater forms of these wastes are expected to be more dilute than the untreated D004 wastewater; and (4) the performance data demonstrate that the arsenic in the D004 wastewater can effectively be removed.

6.2.2 K101 and K102 Wastewaters

The Agency is proposing new wastewater treatment standards for K101 and K102 in today's rule. Standards for these wastewaters were promulgated on August 17, 1988 (53 FR 31170). These standards were based on the same D004 wastewater treatment data used in today's rule to

establish arsenic standards for other K, U, and P wastes. In the process of reevaluating the D004 wastewater treatment data, however, the Agency found an error in the operation of the system used to develop standards for the metal constituents in K101 and K102 wastewaters. The Agency determined that the sand and gravel filter was not properly operated based on an increase in the average total suspended solids (TSS) content from 55 to 64 mg/l. Therefore, the Agency is proposing to amend the wastewater standards for the metal constituents (arsenic, cadmium, lead, and mercury) in K101 and K102. The proposed new treatment standards are 0.79 mg/l for arsenic, 0.24 mg/l for cadmium, 0.17 mg/l for lead, and 0.082 mg/l for mercury. These new standards are based on the same D004 data, but use a different data set than the data used for the development of the promulgated standards. That is, the data representing the wastewater before the wastewater flows through the sand and gravel filter are used instead of the data representing the wastewater contents after filtration. Calculation of the new metals treatment standards is shown in Table 6-2 at the end of the section. The Agency, however, is not changing the standards for the organics present in K101 and K102 wastewaters, since these data are based on treatment using resin adsorption technology located after the filtration unit.

6.3 Selenium Nonwastewaters

6.3.1 D010, P103, P114, U204, and U205 Nonwastewaters

The Agency has no treatment performance data for vitrification of selenium nonwastewaters. Based on the similarities in the chemical behavior of arsenic and selenium, however, the Agency is extrapolating the treatment performance for vitrification of arsenic to the selenium nonwastewaters. EPA believes that the data represent a level of performance that could be achieved for selenium nonwastewaters using vitrification. The Agency is proposing the treatment performance standard of 5.6 mg/l selenium in the leachate using the EP-toxicity test.

6.4 Selenium Wastewaters

6.4.1 D010, P103, P114, U204, and U205 Wastewaters

The Agency has no treatment performance data for chemical precipitation of selenium wastewaters. Based on the similarities in the chemical behavior of arsenic and selenium, the Agency is also proposing to transfer the level of performance achieved by precipitation of arsenic to the selenium in D010, P103, P114, U204, and U205 wastewaters. Thus, the treatment performance standard for these wastewaters is proposed as 0.79 mg/l total selenium.

Table 6-1 Calculation of Treatment Standards for Arsenic

BDAT constituent	Accuracy-corrected concentration					Average treated waste concentration (mg/l)	Variability factor (VF)	Treatment standard (mg/l) (average x VF)
	Sample Set #1	Sample Set #2	Sample Set #3	Sample Set #4	Sample Set #5			
Nonwastewater								
Arsenic EP leachate (mg/l)	2.0	-	-	-	-	2.0	2.8	5.6
Wastewater								
Arsenic (mg/l)	0.580	0.247	0.163	0.204	0.224	0.284	2.78	0.79

- = No data available.

Table 6-2 Calculation of Metal Treatment Performance Standards for K101 and K102 Wastewaters

BDAT constituent	Accuracy-corrected concentration					Average treated waste concentration (mg/l)	Variability factor (VF)	Treatment standard (mg/l) (average x VF)
	Sample Set #1	Sample Set #2	Sample Set #3	Sample Set #4	Sample Set #5			
Arsenic	0.580	0.247	0.163	0.204	0.224	0.284	2.78	0.79
Cadmium	0.085	0.085	0.085	0.085	0.085	0.085	2.8	0.24
Lead	0.060	0.060	0.060	0.060	0.060	0.060	2.8	0.17
Mercury	0.00052	0.004	0.018	0.0024	0.0077	0.0065	12.6	0.082

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APPENDIX A

Industry Information and Characterization Data for Arsenic and Selenium

Table A-1 Current Manufacturers of Arsenic and Selenium Compounds

Industry	Manufacturer	Location	Product(s)
Wood preservation	Hickson Corp.	Conley, GA	Copper chrome arsenate
	Osmose Wood Preserving	Millington, TN	Copper chrome arsenate, arsenic acid
	Mineral Research and Development	Harrisburg, NC	Copper chrome arsenate, arsenic acid
	MR Metals	Laramie, WY	Arsenic acid
	Penwalt	Bryan, TX	Copper chrome arsenate
Pesticides	Vineland Chemical	Vineland, NJ	Cacodylic acid
	Cedar Chemical	Vicksburg, MS	Cacodylic acid
	Fermenta	Houston, TX	Cacodylic acid and salts
	DREXEL Chemical	Tunica, MS	Cacodylic acid and salts
Veterinary pharmaceuticals	Fleming Laboratories	Charlotte, NC	p-aminophenyl arsonic acid
	Salsbury Laboratories	Charles City, IA	4-nitrophenyl arsonic acid
			4 hydroxyl 3 nitrophenyl arsonic acid
Chemical manufacturing	Harshaw Filtrol	Louisville, KY	Cadmium red pigment
	S. Kohnstamm, Inc.	Newark, NJ	
	SCM Corp.	Baltimore, MD	
	Ajay Chemical	Powder Springs, GA	Selenic acid and/or its salts
	Phillip Brothers	Bowmanstown, PA	
	Chemical Company	Quincy, IL	

Source: SRI 1988.

TABLE A-2 CHARACTERIZATION DATA FOR D004 CHARACTERISTIC ARSENIC WASTES

PHYSICAL WASTE DESCRIPTION	WASTE DESCRIPTION	INDUSTRIAL DESCRIPTION	SOURCE OF WASTE GENERATION	QUANTITY	SOLIDS (%)	WATER (%)	ARSENIC CONTENT
Aqueous inorganic liquids	Scrubber water	Industrial inorganic chemicals, nec	Clean out of process equipment	85 T	5	95	10-100ppm
	Leachate	Noncommercial research organizations	Other process	200 G	10	90	0.1-1%
	Wastewater or aqueous mixture	Semiconductors and related devices	Steam cleaning	45 T	5	95	500ppm-0.1%
	Aqueous waste with low other toxic organics	Semiconductors and related devices	Spray rinsing	1,485 G	P	99	1-10ppm
Contaminated soil	Soil contaminated with inorganics only	Agricultural chemicals, nec	Other one time process	53 T	NA	DK	10-100ppm
	Soil contaminated with inorganics only	DK	Other process	21 T	60	40	10-100ppm
	Soil contaminated with organics	Radio and TV communication equipment, Aircraft	Other clean out or closure process	542 T	99	NA	1-10ppm
	Contaminated soil or cleanup residue	Semiconductors and related devices	Clean out of process equipment	1,540 G	99	DK	0.1-1ppm
	Contaminated soil or cleanup residue	Wood preserving	Closure of surface impoundments	DK	66	8	100-500ppm
Inorganic liquids	Other inorganic sludge	Agricultural chemicals, nec	Other clean out or closure process	15 T	30	70	1-10ppm
	Other inorganic sludge	Agricultural chemicals, nec	Other one-time process	11 T	35	65	10-100ppm
	Other inorganic liquid	Agricultural chemicals, nec	Other one time process	3 T	1	99	1-10ppm
	Other inorganic liquid	Agricultural chemicals, nec	Other process	185,713 T	DK	99	10-100ppm
	Other inorganic liquid	Electronic computing equipment	Discarding of out-of-date products or chemicals	1 T	P	P	P
	Other inorganic sludge	Industrial inorganic chemicals, nec	Filtration/centrifuging	60 T	40	60	0.1-1%
	Other inorganic liquid	Industrial inorganic chemicals, nec	Clean out of process equipment	3 T	20	80	0.1-1%
	Other inorganic sludge	Industrial organic chemicals, nec	Clean out of process equipment	5 T	80	20	0.1-1ppm
	Other inorganic liquid	Refuse systems	Other process	2,950,000 G	2	98	1-10ppm
	Spent acid with metals	Semiconductors and related devices	DK	220 G	DK	DK	DK
	Other inorganic liquid	Semiconductors and related devices	Other cleaning/degreasing process	2 T	0	99	10-100ppm
	Other inorganic liquid	Ship building and repairing	Discarding of out-of-date products or chemicals	1 T	DK	DK	P
Inorganic sludges	Degreasing sludge with metal scale or filings	Costume jewelry	Other cleaning/degreasing process	4 T	DK	DK	DK
Inorganic solids	Other inorganic solids	Agricultural chemicals, nec	Dewatering	486 T	70	30	DK
	Other reactive salts/chemicals	Air, water and solid waste management	Discarding of out-of-date products or chemicals	3 T	DK	DK	DK
	Other inorganic solids	Colleges and universities, nec	Other waste production process	5 T	99	1	10-100ppm
	Other inorganic solids	DK	Other cleaning/degreasing process	1 T	NA	0	100-500ppm
	Other inorganic solids	Glass containers	Other process	1,381 T	99	0	0.1-1ppm
	Other inorganic solids	Industrial gases	Other clean out or closure process	31 T	83	17	0.1-1%
	Other inorganic solids	Industrial gases	Other clean out or closure process	1 T	13	87	0.1-1%
	Other metal salts/chemicals	Industrial gases	Cleanup of spill residues	1 T	99	NP	DK
	Other inorganic solids	Industrial inorganic chemicals, nec	Reaction/synthesis media processing	404 T	60	15	1-10%
	Spent solid filters or adsorbents	Industrial inorganic chemicals, nec	Clean out of process equipment	7 T	80	20	0.1-1%
	Spent solid filters or adsorbents	Industrial organic chemicals, nec	Clean out of process equipment	2 T	99	NA	P
	Other inorganic solids	Industrial organic chemicals, nec	Other waste production process	17 T	92	P	1-10%
	Spent solid filters or adsorbents	Industrial organic chemicals, nec	Discarding of out-of-date products or chemicals	1 T	99	0	1-10ppm
	Metal scale, filings or scrap	Industrial organic chemicals, nec	Other waste production process	9 T	NA	NA	0.1-1%
	Other inorganic solids	National security	Size reduction	1 T	DK	DK	P
	Other inorganic solids	Nitrogenous fertilizers	Filtration/centrifuging	1T	99	1	0.1-1%
	Other inorganic solids	Petroleum products, nec, Chemicals and allied products	Other processes	486 G	99	0	P
	Spent solid filters or adsorbents	Petroleum refining	Discarding of off-spec material	483 T	99	0	1-10ppm
	Other inorganic solids	Petroleum refining	Reaction/synthesis media processing	25 T	99	0	1-10ppm
	Other inorganic solids	Petroleum refining	Other one-time process	139 T	DK	0	100-500ppm
	Other inorganic solids	Petroleum refining	Other waste production process	990 G	99	1	P
	Other inorganic solids	Petroleum refining	Other waste production process	16 T	99	DK	DK
	Other inorganic solids	Petroleum refining	Other process	51 T	85	10	1-10%
	Other inorganic sludge	Petroleum refining, Research and development laboratories	Other waste production process	220 G	99	0	P
	Metal scale,filings or scrap	Primary nonferrous metals, nec	Filtration/centrifuging	306 T	100	NA	1-10%
	Spent solid filters or adsorbents	Research and development laboratories	Closure of process equipment	110 G	99	0	P
	Spent solid filters or adsorbents	Semiconductors and related devices	Other waste production process	1 T	99	0	10-25%
	Other waste inorganic chemicals	Semiconductors and related devices	Other waste production process	2 T	99	0	1-10%
	Other inorganic solids	Semiconductors and related devices	Fill and gravity draining	5 T	NA	NA	1-10%
	Other waste inorganic chemicals	Semiconductors and related devices	Physical scraping/removal	96 G	100	0	100-500ppm
	Other inorganic solids	Semiconductors and related devices	Other processes	100 T	99	0	10-100ppm
	Other inorganic solids	Semiconductors and related devices	Clean out of process equipment	1 G	99	0	0.1-1%
	Other waste inorganic chemicals	Semiconductors and related devices	Stripping	120 G	100	0	500ppm-0.1%
	Spent solid filters or adsorbents	Semiconductors and related devices	Filtering/screening	192 G	NA	0	1ppb-0.1ppm
			Filtering/screening	120 G	DK	DK	10-25%

TABLE A-2 CHARACTERIZATION DATA FOR D004 CHARACTERISTIC ARSENIC WASTES

PHYSICAL WASTE DESCRIPTION	WASTE DESCRIPTION	INDUSTRIAL DESCRIPTION	SOURCE OF WASTE GENERATION	QUANTITY	SOLIDS (%)	WATER (%)	ARSENIC CONTENT
Inorganic solids (cont.)	Other inorganic solids	Semiconductors and related devices	Other one-time process	1 T	99	0	1-10%
	Other metal salts/chemicals	Semiconductors and related devices	Other waste production process	1 T	NA	NA	1ppb-0.1ppm
	Other inorganic solids	Semiconductors and related devices	Closure of process equipment	1 T	99	NA	0.1-1%
	Other inorganic solids	Semiconductors and related devices	Clean out of process equipment	3 T	NA	NA	0.1-1%
	Other inorganic solids	Semiconductors and related devices	Clean out of process equipment	1 T	99	DK	DK
	Other inorganic solids	Semiconductors and related devices	Clean out of process equipment	48 G	100	NA	500ppm-0.1%
	Other inorganic solids	Semiconductors and related devices	Other cleaning./degreasing process	2 G	99	0	10-100ppm
	Other inorganic solids	Semiconductors and related devices	Reaction/synthesis media processing	5 T	99	0	0.1-1ppm
	Other inorganic solids	Space vehicle equipment, nec	Other waste production process	18 T	95	5	DK
	Metal scale, filings or scrap	Special warehousing and storage	Other pollution control or waste treatment process	497,856 G	50	DK	P
	DK	Plating and polishing, Semiconductors and related devices	Surface coating	3 T	99	0	10-25%
	Spent solid filters or adsorbents	Wood preserving	Filtration/centrifuging	DK	DK	DK	>90%
	Other inorganic liquid	Wood preserving	Tank bottoms removal	210 G	85	10	1-10%
Lab packs	Lab packs of old chemicals only	Agricultural chemicals, nec	Laboratory wastes	5 G	DK	DK	25-50%
	Lab packs of old chemicals only	Colleges and universities	Laboratory wastes	5 G	DK	DK	10-25%
	Lab packs of old chemicals only	Colleges and universities, nec	Discarding of out-of-date products or chemicals	1 T	DK	DK	25-50%
	Mixed lab packs	Colleges and universities, nec	Discarding of off-spec material	1 T	NA	NA	P
	Lab packs of old chemicals only	Colleges and universities, nec	Laboratory wastes	DK	NA	NA	50-75%
	Other inorganic liquid	Colleges and universities, nec	Laboratory wastes	220 G	5	95	DK
	Other inorganic liquid	Colleges and universities, nec	Laboratory wastes	1 T	P	99	500ppm-0.1%
	Other inorganic solids	DK	Discarding of out-of-date products or chemicals	180 G	99	1	75-90%
	Lab packs of debris only	Electronic components,nec,Space vehicle equipment, nec	Laboratory wastes	1 T	99	NA	1-10%
	Other inorganic solids	Electronic components, nec	Laboratory wastes	275 G	99	DK	25-50%
	Lab packs of old chemicals only	Explosives	Discarding of out-of-date products or chemicals	72 G	DK	DK	DK
	Other aqueous waste with low dissolved solids	General government, nec	Laboratory wastes	1 G	0	DK	DK
	Other inorganic liquid	Industrial inorganic chemicals, nec	Laboratory wastes	19 G	P	50	1-10%
	Empty or crushed metal drums or containers	Industrial inorganic chemicals, nec	Discarding of contaminated cleanup equipment	20 T	95	5	0.1-1%
	Other inorganic solids	National security, Ammunition, except for small arms, nec	Laboratory wastes	1 T	NA	NA	>90%
	Mixed lab packs	Ordnance and accessories, nec	Discarding of off-spec material	199 G	20	NA	DK
	Mixed lab packs	Pressed and blown glass, nec	Other one-time process	1 G	DK	DK	DK
	Lab packs of debris only	Semiconductors and related devices	Clean out of process equipment	5 T	DK	DK	500ppm-0.1%
	Mixed lab packs	Semiconductors and related devices	Laboratory wastes	1 T	99	0	DK
	Lab packs of old chemicals only	Surgical and medical instruments	Discarding of out-of-date products or chemicals	1 T	NA	0	50-75%
Organic liquids	Other organic liquid	Agricultural chemicals, nec	Wastewater treatment	6,612,000 G	0.02	99	1ppb-0.1ppm
	Other organic liquid	Agricultural chemicals,nec	Other one-time process	37,500 G	1	99	10-100ppm
	Other organic liquid	DK	Discarding of off-spec material	0	1	0	1-10%
	Waste oil	Electronic computing equipment, Semiconductors	Clean out of process equipment	0	NA	NA	1-10ppm
	Other organic liquid	Nitrogenous fertilizers	By-product processing	134,000 G	1	5	10-100ppm
	Waste oil	Semiconductors and related devices	Other waste production process	5 T	0	0	1-10ppm
	Waste oil	Semiconductors and related devices	Clean out of process equipment	215 G	DK	0	1-10ppm
	Waste oil	Semiconductors and related devices	Clean out of process equipment	55 G	DK	DK	DK
	Nonhalogenated solvent	Semiconductors and related devices	Flush rinsing	110 G	0.1	50	500ppm-0.1%
Organic solids	Other nonhalogenated organic solid	Chemical products, nec	Other clean out or closure process	11 T	100	0	25-50%
	Other nonhalogenated organic solid	Chemical products, nec	Other clean out or closure process	1 T	43	57	0.1-1%
	Other halogenated organic solid	Industrial organic chemicals, nec	Other waste production process	195 T	85	5	10-100ppm
	Spent carbon	Industrial organic chemicals, nec	Clean out of process equipment	3 T	60	40	DK
	Other nonhalogenated organic solid	Industrial organic chemicals, nec	Discarding of contaminated cleanup equipment	1 T	NA	NA	10-100ppm
	Other nonhalogenated organic solid	Surface active agents	Other processes	192 G	DK	DK	P

DK = DON'T KNOW
G = GALLONS
NA = NOT AVAILABLE
NP = NOT PRESENT
P = PRESENT
T = TONS

Reference: USEPA 1989b

Table A-3 Waste Characterization Data for K031

Constituents (ppm)	Data sources (1)	(2)	(3)	(4)	(5)	(6)	(7)
BOAT List Organics:							
Methylene chloride	-	-	-		14	11	-
BOAT List Metals:							
Arsenic	10,000	6,300	-	-	15,000.	180,000	1,000.-10,000
Barium	-	0.5	-	-	-	-	-
Cadmium	-	4.6	-	-	-	-	-
Chromium	-	26	-	-	-	-	-
Others:							
Ash content	-	-	920,000.-980,000	-	-	-	-
Baron	0.02	-	-	-	-	-	-
Bicarbonate	1,800	-	-	-	-	-	-
Cacodylate contaminants				10,000.-15,000	-	-	-
Calcium	116	-	-	-	-	-	-
Carbonate	3,920	-	-	-	-	-	-
COD	-	-	10,500	18,500	-	-	-
MSMA (as arsenic)	-	-	5,000.-14,000	-	-	-	-
Nitrate	0.06	-	-	-	-	-	-
Sodium chloride	400,000.-600,000	400,000.-500,000	-	-	-	-	-
Sodium sulfate	400,000.-600,000	400,000.-500,000	-	-	-	-	-
Solids	-	300,000.	950,000.-990,000	-	-	-	-
Solid content (%)	-	-	-	-	-	-	95
Water content (%)	-	-	-	-	-	-	5

Reference:

(1) MSMA and cacodylic acid waste (Environ 1985).

(2) MSMA salt cake (Environ 1985).

(3) MSMA acid waste (Environ 1985).

(4) Solid waste that is a mixture of sodium chloride and sodium sulfate generated during cacodylic acid production (Environ 1985).

(5) K031 acidifier (USEPA 1988f).

(6) K031 tank bottoms (USEPA 1988f).

(7) Reported arsenic content for 1,759,841 tons of K031 (USEPA 1989a).

Table A-4 Waste Characterization Data for K084

Constituents (ppm)	Data sources									
	(1)	(2)	(3)	(4)	(4)	(5)	(5)	(5)	(5)	(5)
BOAT List Organics:										
1,1-Dichloroethene	1,400	400	680	-	-	-	-	-	-	-
1,1,2-Trichloroethene	70	900	760	-	-	-	-	-	-	-
Phenol	240	360	570	-	-	-	-	-	-	-
4-Nitrophenol	342	258	20,020	-	-	-	-	-	-	-
BOAT List Metals:										
Arsenic	45,200	47,400	9,760	-	10,000.-70,000		1-10%	1-10%	10-25%	10-25%	10-100
Others:										
Arsenic acid (as arsenic)	-	-	-	<3,500	-	-	-	-	-	-
COD	9,700	65,500	109,000	-	-	-	-	-	-	-
pH	-	-	-	6-8	-	-	-	-	-	-
Sulfate	641	5,220	6,080							
Sodium arsenates (as arsenic)	-	-	-	160,000.-200,000	-	-	-	-	-	-
Sodium	-	-	-	80,000.-100,000	-	-	-	-	-	-
Solids (%)	-	-	-	300,000	-	30	28	28	33	15
TOC	12,900	75,300	156,000							
Water (%)	74.1	73.8	76.5	50	50	70	72	72	67	85

(1) USEPA 1987a (K084 calcium precipitate).
(2) USEPA 1987a (K084 manganese precipitate).
(3) USEPA 1987a (K084 iron precipitate).
(4) Environ 1985.
(5) USEPA 1989a.
- No data available.

Table A-5 Waste Characterization Data for K101 and K102

Constituents (ppm)	Untreated K101 waste concentration ranges	Untreated K102 waste concentration ranges
BDAT List Volatile Organics		
Acetone	<50 - 81	ND
Toluene	<25 - 42	5.4 - 26
Total Xylenes	ND	<1.5 - 5.3
BDAT List Semivolatile Organics		
Bis(2-ethylhexyl)phthalate	<36,000 - <38,000	<19.4 - <194
Phenol	ND	<19.4 - <194
BDAT List Metals		
Antimony	<3.3 - 7.4	8,960 - 18,800
Arsenic	590 - 1,950	3,060 - 8,320
Barium	3.5 - 108	16 - 52
Beryllium	<0.1	<0.10 - 0.20
Cadmium	<5.0	8.9 - 26
Chromium	2.0 - 22	16 - 22
Copper	128-289	4.7 - 6.6
Lead	<0.5 - 6.7	1.6 - 25.9
Mercury	1.5 - 4.2	<0.1 - 3.5
Nickel	1.8 - 5.4	<1.1 - 13
Selenium	<0.5	9.1 - 17
Silver	<0.7 - 1.6	<0.7
Thallium	<5.0	<1.0 - 2.1
Vanadium	<0.4 - 1.7	<0.40 - 0.58
Zinc	35 - 111	3.1 - 8.7
BDAT List Inorganics		
Cyanide	<0.67	3.21 - 5.06
Fluoride	7.74	4.35
Sulfide	65.6 - 778	4,250 - 8,150
Other Analyses		
2-Nitroaniline	<172,000 - 191,000	ND
2-Nitrophenol	ND	220-870
Chlorides	9,960 - 38,700	336 - 7,080
Sulfate	5,690 - 11,800	37 - 338
Total solids	604,000 - 804,000	333,000 - 395,000
Total organic carbon	254,900 - 407,400	163,100 - 216,500

ND - Not detected.

Source: USEPA 1988a.

Table A-6 Waste Characterization for P010, P011, and P012 Wastes

RCRA waste codes	Waste description	Waste source	Solids %	Water %	Arsenic content	1986 quantity generated
P010	Contaminated soil or cleanup residue	Cleanout of process equipment	DK	DK	500 ppm	1,010 G
	Other untreated waste	Physical scraping	99	0	0.1-1 ppm	250 G
	Other inorganic liquid	Laboratory wastes	0	0	50-75%	1 G
D004,D007,P011	Contaminated soil or cleanup	Tank bottoms removal	70	30	1-10%	1 T
D002,D004,P011	Other inorganic sludge	Filtration/centrifuging	80	20	1-10%	26 T
D002,9,P011,P098	Metal-cyanide salts/chemicals	Discarding of off-spec chemicals	99	1	10-25%	1 T
D001,2,4,7,P011	Mixed lab packs	Laboratory wastes	100	0	25-50%	1 T
P012	Other F/K wastes, as described	Discarding of out-of-date products/chemicals	99	0	25-50%	1 T

Reference: USEPA 1989a.
DK = Don't know
G = Gallons
T = Tons

TABLE A-7 CHARACTERIZATION DATA FOR D010 CHARACTERISTIC SELENIUM WASTES

WASTE CATEGORY	WASTE DESCRIPTION	INDUSTRIAL DESCRIPTION	SOURCE OF WASTE GENERATION	QUANTITY	SOLIDS (%)	WATER (%)	SELENIUM CONTENT
Aqueous inorganic liquids	Wastewater or aqueous mixture	Electronic computing equipment	Electroplating	2 G	DK	85	0.1-1%
	Aqueous waste with low solvents	Blast furnaces and steel mills,Petroleum and coal products	Quench cooling	381,501 T	1	98	1-10ppm
Inorganic liquids	Other inorganic liquid	Petroleum refining	Oxidation (other than combustion)	229,350 T	0	98	1-10ppm
	Spent acid with metals	Hardware, nec	Electroplating	26,000 G	DK	DK	10-100ppm
Inorganic sludges	Untreated plating sludge without cyanides	Plating and polishing,electronic components, nec	Electroplating	4250 G	90	10	1-10ppm
	Other wastewater treatment sludge	Petroleum refining	Wastewater treatment	27,489 G	11	77	1-10ppm
Inorganic solids	Metal scale,filings,or scrap	Special warehousing and storage, nec	Other pollution control or waste treatment process	443,800 G	90	DK	P
	Other waste inorganic chemicals	Semiconductors and related devices	Discarding of off-spec material	1 T	99	0	P
	Other inorganic solids	National security, space research and technology	Other cleanout or closure process	1 T	DK	DK	P
	Other metal salts/chemicals	Hardware, nec,Plating and polishing	Tank bottoms removal	55 G	80	20	0.1-1%
	Other inorganic solids	Coating, engraving,and allied services	Physical scraping/removal	4 T	100	0	P
	Other metal salts/chemicals	Chemical preparations, nec	Materials handling	6 T	99	1	1-10ppm
Lab packs	Concentrated off-spec or discarded product	Plastics materials and resins	Materials handling	13 T	100	0.5	1-10ppm
	Lab packs of old chemicals only	Electronic computing equipment	Discarding of out-of-date products or chemicals	1 T	99	0	P
	Lab packs of old chemicals only	Colleges and universities, nec	Laboratory wastes	0	DK	DK	10-25%
	Other inorganic liquid	Colleges and universities, nec	Laboratory wastes	1 T	P	99	100-500ppm
Organic liquids	Other organic liquid	Toilet preparations, Soap and other detergents	Other process	13300	2	90	100-500ppm
Organic solids	Other nonhalogenated organic solid	Petroleum refining	Clean out of process equipment	1 T	99	0	10-100ppm
	Solid resins or polymerized organics	Paint shops,Metal coating and allied services	Physical scraping/removal	25 T	DK	DK	DK

DK = DON'T KNOW
G = GALLONS
P = PRESENT
T = TONS

REFERENCE: USEPA 1989b

APPENDIX B

High-Temperature Stabilization Technologies

B.2 Underlying Principles of Operation

The basic principles of operation for high-temperature stabilization technologies are dependent on the technology used. In glass and slag vitrification processes, the waste constituents become chemically bonded inside a glasslike matrix in many cases. In all instances, the waste becomes surrounded by a glass matrix. This acts to immobilize the waste constituents and to retard or prevent their reintroduction into the environment. Arsenates are converted to silicoarsenates, and other metals are converted to silicates.

High-temperature calcination processes remove water of hydration from the toxic metal-bearing solids, convert hydroxides present to oxides, and sinter the material, reducing its surface area to a minimum. Conversion of hydroxides to oxides and minimization of available surface area retard surface reactions that would reintroduce the material into the environment. Calcination may also be accompanied by chemical reaction if a material such as lime is blended with the waste before it is heated. For example, lime will react with arsenic oxides at higher temperatures to form calcium arsenate, and this material will then be sintered at elevated temperatures. Brief descriptions of each of the high-temperature processes are given below.

B.2.1 Glass Vitrification

In the glass vitrification process, the waste and normal glassmaking constituents are first blended together and then fed to a glassmaking furnace, where the mixed feed materials are introduced into a pool of molten glass. The feed materials then react with each other to form additional molten glass, in which particles of the waste material become dissolved or suspended. The molten glass is subsequently cooled. As it cools, it solidifies into a solid mass that contains the dissolved and/or

suspended waste constituents. Entrapment and chemical bonding within the glass matrix renders the waste constituents unavailable for reaction.

B.2.2 Slag Vitrification

Slag vitrification differs from glass vitrification in that finely ground slag from metal-refining processes and waste are premixed and fed to the same type of furnace as that used for glassmaking. The slag liquifies at the process temperature (1100 to 1200°C), and the waste constituents either dissolve or become suspended in the molten slag. Subsequent cooling of the slag causes it to solidify, trapping the waste inside a glasslike matrix and rendering it unavailable for chemical reaction or migration into the environment.

B.2.3 High-Temperature Calcination

In the high-temperature calcination process, the waste is heated in a furnace or kiln to between 400 and 800°C. In some instances, the waste may be blended with lime prior to heating. In those cases, chemical reaction may occur during the calcining process. Water present as either free water or water of hydration is evaporated, and hydroxides present are thermally decomposed to the corresponding oxides and water vapor. At the higher temperatures, the surface area of the dehydrated material is decreased by thermal sintering. Conversion of hydroxides to oxides and substantial losses of surface area render the material less reactive in the environment and lower the leachability of EP toxic metals present. In general, the higher the calcination temperatures used, the more complete is the loss of water and the greater is the accompanying loss of surface area, resulting in lower leachability potential.

B.3 Description of the High-Temperature Stabilization Processes

This chapter discusses three types of high-temperature stabilization processes, which differ considerably from each other. Individual process descriptions are given in the following subsections.

B.3.1 Glass Vitrification

Soda ash, lime, silica, boron oxide, and other glassmaking constituents are first blended with the waste to be treated. The amount of waste added to the blend is dependent on the waste composition. Different metal oxides have differing solubility limits in glass matrices. The blended waste and glass raw material mixture is then fed to a conventional, heated glass electric furnace.

The introduced material typically is added through a port at the top of the furnace and falls into a pool of molten glass. The glass constituents dissolve in the molten glass and form additional glass. Molten glass is periodically withdrawn from the bottom of the furnace and cooled. This material then solidifies on cooling into solid blocks of glasslike material. Organics present in the feed mixture undergo combustion at the normal operating temperatures of 1100 to 1400°C and are fully oxidized to carbon dioxide and water vapor.

The top of the furnace is normally cooled so that volatile materials, such as arsenic oxides, that are present in the feed mixture condense on the cooled surface and fall back into the melt, where they can undergo chemical reaction to form silicoarsenates involved in the glassmaking process. Most of the arsenic used in making glass by this method is present as salts such as calcium arsenate. This approach was introduced into the glass industry to minimize fugitive arsenic losses.

Gases, such as carbon dioxide, that are liberated during the glassmaking process exit the furnace through the top and are generally wet-scrubbed prior to reentering the atmosphere.

B.3.2 Slag Vitrification

The slag vitrification process is basically similar to glass vitrification except that granulated slag, instead of the normal glassmaking constituents, is blended with the waste for feed to the system. A pool of liquid slag is present in the furnace, and the blended raw material mix typically is introduced at the top of the furnace and falls into this molten slag. The granulated slag-waste mixture liquifies to form additional slag. Slag is periodically withdrawn from the slag pool and cooled into blocks.

The type of furnace used for glass vitrification can also be used for slag vitrification. The operating parameters are similar.

B.3.3 High-Temperature Calcination

In the high-temperature calcination process, wastes containing inorganic compounds are fed to ovens or kilns, where they are heated to high temperatures (i.e., 500 to 900°C) to drive off water of hydration and to convert hydroxides present to the corresponding oxides. This process is primarily applicable to inorganic wastes that contain nonvolatile constituents.

The waste is heated in the oven or kiln to the desired temperature, moisture and water of hydration are driven off, and, at the 500 to 900°C temperature range, hydroxides decompose to the corresponding oxides and water vapor. The high-temperature treatment also significantly reduces the surface areas of the oxides formed by

sintering, thereby reducing the reactivity of the material. After the waste material has been calcined at an elevated temperature, it is withdrawn from the oven or kiln, cooled, and either land disposed or forwarded to another process such as stabilization for further treatment.

B.4 Waste Characteristics Affecting Performance (WCAPs)

The waste characteristics affecting performance are different for the two vitrification processes and the calcination process. Accordingly, they are discussed separately in the following subsections.

B.4.1 Waste Characteristics Affecting Performance of Vitrification Processes

In determining whether vitrification will achieve the same level of performance on an untested waste as on a previously tested waste, and whether performance levels can be transferred, EPA examines the following waste characteristics that affect performance of the vitrification processes: (1) organic content of the waste, (2) concentrations of specific metal ions in the waste, (3) concentrations of compounds in the waste that interfere with the glassmaking process, and (4) moisture content of the waste.

(1) Organic content. At process operating temperatures (1100 to 1400°C), organics are combusted to carbon dioxide, water, and other gaseous products. The combustion process liberates heat, reducing the external energy requirements for the process.

The amount of heat liberated by combustion is a function of the Btu value of the waste. The Btu content merely changes the energy input needs for the process and does not affect waste treatment performance. The amount of material that may not oxidize completely is a function of

the organic halogen content of the waste. The presence of these halogenated organics does impact process performance because sodium chloride has a low solubility in glass. The presence of high chlorides results in a porous glass that is undesirable. If the halogenated organic content of an untested waste is the same as or less than that present in an already tested waste, the system should achieve the same performance for organic destruction.

(2) Concentrations of specific metal ions. Most metal oxides have solubility limits in glass matrices. Hence, their concentration determines the amount of glass-forming materials or slag with which they must be reacted in this process to generate a nonleaching slag or glass. The solubility limits of most common metal oxides and salts in glass are found in the Handbook of Glass Manufacture and other treatises on glass production. Oxides for which extensive solubility information is available are alumina, antimony oxide, arsenic oxides, barium oxide, cadmium oxide, chromium oxides, copper oxides, cobalt oxides, iron oxides, lead oxides, manganese oxides, nickel oxides, selenium oxides, tin oxides, and zinc oxides. Analysis for individual metal concentrations in the waste can be performed according to EPA-approved methods. If the concentrations of specific metals in an untested waste are less than those in a tested waste, then the same ratio of slag or glass raw materials to waste may be used for vitrification purposes. If, however, the concentration of metal is greater than that in the tested waste, a different formulation must be used.

(3) Concentrations of deleterious materials. Some waste constituents, such as chlorides, fluorides, and sulfates, interfere with the vitrification process if present at high levels. These salts have limited solubilities in glass; therefore, when they are present, additional glass-forming raw materials must be added to compensate for their presence. The solubility limits of various salts in glasses are

discussed in references on glass production such as the Handbook of Glass Manufacture. Generally, if the concentrations of such materials in an untested waste are lower than those in a tested waste, then the same ratio of glass-forming constituents to waste may be used. Reducing agents such as carbon or ferrous salts reduce arsenates and selenates to lower valence compounds that are more volatile. These properties should not be present when vitrifying arsenic or selenium.

(4) Moisture content. Materials fed to the vitrification process should be reasonably dry (i.e., contain less than 5 percent free moisture). If a waste has excess moisture above this level, it should be thermally dried before it is blended with glass-forming materials, as it may react violently when introduced to the molten glass or slag pool.

B.4.2 Waste Characteristics Affecting Performance of High-Temperature Calcination

In determining whether high-temperature calcination will achieve the same level of performance on an untested waste as on a previously tested waste, and whether performance levels can be transferred, EPA examines the following waste characteristics that impact the performance of the high-temperature calcination process: (1) the organic content of the waste, (2) the moisture content of the waste, and (3) the inorganic composition of the waste. These characteristics are discussed below.

(1) Organic content. Calcination temperatures normally used are too low to initiate combustion of some types of organic compounds. However, they are high enough to cause volatilization of organics, which have to be removed from process off-gases. For these reasons, the presence of significant levels of organics is undesirable but can be handled with appropriate air pollution controls. Organics, per se, do not interfere with the conversion of oxides to hydroxides or with sintering processes.

(2) Moisture content. Excess water that has to be removed from the waste by heating increases the amount of time needed to bring the waste to the calcination temperature. For this reason, wastes with high moisture content should be dewatered prior to the use of this process.

(3) Inorganic composition. Calcination temperatures are normally selected based on the temperatures at which hydroxides are thermally decomposed to the corresponding oxides and water vapor. To select an optimum operating temperature, the approximate composition of the waste should be known.

A few toxic metal oxides have fairly low volatilization temperatures. Arsenic oxide, selenium dioxide, and mercuric oxide all volatilize below 500°C. High-temperature calcination should not be used for wastes that contain these volatile constituents unless they are blended with materials such as lime, which will react with them before they can vaporize. Nonvolatile arsenic compounds such as ferric and calcium arsenates may be calcined without concern for vaporization of material.

B.5 Design and Operating Parameters

The design and operating parameters for the vitrification processes are similar to each other, but differ considerably from those for high-temperature calcination. The following subsections discuss these two technologies separately.

B.5.1 Design and Operating Parameters for Vitrification Processes

In assessing the effectiveness of the design and operation of a vitrification system, EPA examines the following parameters: (1) the

composition of the vitrifying agent, (2) the operating temperature, (3) the residence time, and (4) the vitrification furnace design.

(1) Composition of the vitrifying agent. Slag and various glassmaking formulations are used as vitrifying agents. The choice of the vitrifying agent is determined by the solubility of the waste constituents to be vitrified. Different inorganic oxides have differing solubilities in various glass matrices.

For slags, the presence of carbon or other reducing agents is undesirable when vitrifying arsenic-bearing or selenium-bearing wastes. Carbon or ferrous salts in the slag reduce arsenates in the waste to arsenic trioxide, which has a low volatilization temperature. Likewise, these same reducing agents reduce selenates to elemental selenium, which also has a low volatilization temperature. When slags are used for vitrifying arsenic-bearing and selenium-bearing wastes, EPA monitors the composition of the granulated slags to ensure that they do not contain significant concentrations of carbon or ferrous salts.

In glass vitrification, various glassmaking formulations can be used. EPA examines the proposed formulations to ensure that the toxic metal ion concentrations of the final product do not exceed solubility limits. Hence, EPA examines the material balances based on waste composition and glassmaking additives and the published solubility limits for metal oxides in various glasses to ensure that the vitrified product is indeed a glass containing the solubilized toxic waste constituents.

(2) Operating temperature. Vitrification furnaces are normally operated in the 1100 to 1400°C range. The exact operating temperature is usually selected based on the desired composition of the final product. Furnaces are normally equipped with automatic temperature control systems.

EPA examines the basis of choice for operating temperatures and the nature and physical condition of the temperature monitoring and control equipment to ensure that the system is being properly operated.

(3) Residence time. Sufficient time must be allowed for the materials added to glass furnaces to reach operating temperatures and then undergo the chemical reactions needed to produce glasses. Residence times are normally on the order of 1 to 2 hours for processes operated at 1100 to 1200°C. For glasses or slags requiring slightly higher temperatures, slightly longer residence times are usually selected. EPA examines the basis for the facility's choice of residence times to ensure that the system is well operated.

(4) Vitrification furnace design. Vitrification furnaces normally incorporate the following design features:

- Withdrawal of the product in liquid form from the base of the furnace.
- Maintenance of a liquid pool of product in the furnace.
- Addition of product constituent mix at the top of the furnace.
- Design of the top area of the furnace in a manner that allows for cooling of this area. (This is important because volatile constituents of the input feed may vaporize from the melt. The cool top area allows these constituents to condense and fall back into the melt.)
- Presence and proper operation of an air emissions control scrubbing system to manage vent gas emissions from the system such as hydrogen chloride vapors from combustion of any chlorinated organics present.

EPA examines the furnaces to be used for waste vitrification to ensure that the design features mentioned above are present, since they are important for proper operation of the systems.

B.5.2 Design and Operating Parameters for High-Temperature Calcination Systems

In assessing the effectiveness of the design and operation of a high-temperature calcination process, EPA examines the following parameters: (1) operating temperature, (2) residence time, and (3) air emission control units in place on the ovens or kilns used.

(1) Operating temperatures. Calcination temperatures of from 500 to 900°C have been used in practice. The calcination temperature selected is generally a temperature above which metal hydroxides present will decompose to the corresponding oxides. Data on decomposition temperatures of some metal hydroxides are given in Table B-1. The temperature chosen is normally high enough to cause extensive sintering (surface area loss) of the oxides formed, while at the same time not volatilizing these materials. EPA examines the technical basis for selection of the calcining temperature to determine whether the system is properly operated. EPA also examines the temperature monitoring and control systems in place to determine whether they are properly operated and reliable.

Table B-1 Metal Hydroxide Decomposition Temperatures

Metal hydroxide	Decomposition temperature (°C)
Cadmium hydroxide	300
Chromic acid	400
Lead hydroxide	145
Nickel hydroxide	230
Zinc hydroxide	125

Source: Weast 1977.

(2) **Residence time**. Calcination is generally a batch process, and sufficient time must be allowed for samples to be brought to the operating temperature. Residence times of several hours are normally used to minimize the effects of heat-up time. EPA examines the technical basis for the choice of residence time to ensure that sufficient heating at the required temperature is allowed to complete the dehydration and sintering processes. Residence time is a function of the time needed to bring the calcination furnace or kiln to the desired temperature and the time needed to complete the dehydration and sintering processes at the selected temperature.

(3) **Air emissions control systems**. During the calcination process, water vapor is driven off as it is formed by the decomposition of hydroxides present in the waste. These hot gases exit the calcination furnace or kiln as they are formed. Some particulates of the waste material may become entrained in these vent gases; therefore, for air pollution control purposes, the calcination units must be equipped with wet or dry particulate collection systems that are properly designed and operated. EPA examines the design basis, physical condition, and maintenance of these air emissions control units to determine whether they are properly designed, maintained, and operated. EPA also examines the system of management in use for handling and subsequent treatment of the collected particulates to ensure that these finely divided waste particles are properly managed.

B.6 References

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APPENDIX C

Treatment Performance Data Base for Arsenic and Selenium Wastes

Table C-1 Stabilization Treatment Performance Data for Arsenic Wastes

Treatment process	Waste type	Arsenic concentration in EP-toxicity leachate	
		Untreated (mg/l)	Treated (mg/l)
Cement stabilization	K031	533	102
	Arsenic sulfide	41	127
	Smelter dust	6450	8350
Cement stabilization	K031	533	205
	Arsenic sulfide	41	46.5
	Smelter dust	6450	4520
Cement stabilization	K031	533	42.3
	Arsenic sulfide	41	115
Urea formaldehyde resin encapsulation	K031	533	356
	Arsenic sulfide	41	5.2
	Smelter dust	6450	1980
Urea formaldehyde resin encapsulation	Arsenic sulfide	41	6.7
	Smelter dust	6450	498
Asphalt encapsulation	K031	533	25.3
	Arsenic sulfide	41	1.7
	Smelter dust	6450	61.8
Silicate polymer fixation	K031	533	128
	Arsenic sulfide	41	162
	Smelter dust	6450	0.73
Clay stabilization	K031	533	278
	Arsenic sulfide	41	97
	Smelter dust	6450	6050
Cement and sodium silicate fixation	K031	533	74.5
	Arsenic sulfide	41	27.3
	Smelter dust	6450	3860
Silicate fixation	K031	533	73.0
	Arsenic sulfide	41	43.3
	Smelter dust	6450	5900
Lime-fly ash stabilization	K031	533	35.8
	Arsenic sulfide	41	21.9
	Smelter dust	6450	780
Polyethylene encapsulation	K031	533	139
	Arsenic sulfide	41	71

Source: JBF Scientific 1978.

Table C-2 Stabilization Treatment Performance Data for K031

Constituents	Untreated K031 waste		Stabilized waste using cement			Stabilized waste using lime/fly ash			Stabilized waste using kiln dust		
	Total (mg/kg)	TCLP (mg/l)	Test #1 TCLP (mg/l)	Test #2 TCLP (mg/l)	Test #3 TCLP (mg/l)	Test #1 TCLP (mg/l)	Test #2 TCLP (mg/l)	Test #3 TCLP (mg/l)	Test #1 TCLP (mg/l)	Test #2 TCLP (mg/l)	Test #3 TCLP (mg/l)
BDAT List Metals											
Antimony	456	18.5	11.9	12.7	12	16	16.1	16	14.8	14.7	14.7
Arsenic	133,000	5,930	6,535	5,334	5,792	4,687	4,888	5,713	5,856	5,402	5,544
Barium	0.30	0.081	0.5	0.5	0.42	0.25	0.31	0.37	0.3	0.31	0.33
Beryllium	ND	ND	0.003	0.002	0.002	0.0025	0.003	0.002	0.002	0.002	0.001
Cadmium	375	16	1.9	2	2	1.9	1.9	1.9	1.9	1.9	1.8
Chromium	1.3	0.025	0.12	0.11	0.12	0.07	0.07	0.07	0.1	0.09	0.08
Copper	14	0.494	1.1	0.86	0.66	ND	ND	ND	1	1.3	1.8
Lead	151	5.95	1.8	1.6	1.4	7	7.1	7.5	3.5	3.8	3.4
Mercury	0.17	0.0022	0.0023	0.003	0.003	0.0003	0.0006	0.0009	0.0013	0.003	0.002
Nickel	47	1.79	1.2	1.2	1.2	1.4	1.3	1.3	1.1	1.1	1.1
Selenium	3.1	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Silver	ND	ND	0.02	0.01	0.01	ND	ND	ND	ND	ND	ND
Thallium	ND	ND	0.09	0.05	0.08	0.05	0.05	0.05	0.08	0.07	0.08
Vanadium	ND	ND	0.1	0.11	0.1	0.08	0.09	0.09	0.13	0.13	0.12
Zinc	3.5	0.217	0.86	0.97	0.68	2.4	3	8.8	1.3	2.8	1.9
Other Parameters											
Sulfate	46,600	-	-	-	-	-	-	-	-	-	-
Chloride	211,000	-	-	-	-	-	-	-	-	-	-
Oil & grease	191	-	-	-	-	-	-	-	-	-	-
Total organic carbon (Avg.)	21,100	-	-	-	-	-	-	-	-	-	-

- = No data available.

ND = Not detected.

Source: USEPA 1988f.

Table C-3 Stabilization Treatment Performance Data for Proprietary Process

Analysis	Arsenic concentration			
	Untreated		Treated	
	Sample #1	Duplicate	Sample # 1	Duplicate
Mix A				
Total composition (mg/kg)	7,880	9,150	--	2,140
EP-toxicity (mg/l)	268	263	21.2	20.9
TCLP (mg/l)	--	243	50	78.0
Mix Z				
Total composition (mg/kg)	7,880	9,150	--	5,640
EP-toxicity (mg/l)	268	263	13.0	68.0
TCLP leachate (mg/l)	--	243	109.5	288.2

- = No data available.

Reference: Price 1989.

Table C-4 Effect of the pH on the Stability of Ferric Arsenate Precipitates

Ferric-to-arsenic ratio (wt %)	pH	Leachate concentration (mg/l)	
		Arsenic	Iron
3.89	3.0	0.095	3.9
	4.0	0.080	0.08
	5.0	0.27	<0.05
	6.0	1.13	0.46
	7.0	10.3	6.7
	8.0	31	16.6
	9.0	67	39.4
7.63	3.0	0.08	2.0
	5.0	0.27	0.17
	7.0	0.11	0.23
	9.0	15	2.6
17.1	3.0	<0.05	1.5
	4.0	<0.05	0.05
	5.0	<0.05	<0.05
	6.0	0.07	0.05
	7.0	0.08	0.10
	8.0	0.09	0.21
	9.0	0.94	1.6

Operating conditions
Temperature = 25°C

Source: Krause and Ettel 1985.

Table C-5 EP-Toxicity Testing of Calcium Arsenate-Containing and Calcium Selenate-Containing Precipitates

Sample	Arsenic total concentration (mg/kg)	Arsenic EP-toxicity leachate (mg/l)	Selenium total concentration (mg/l)	Selenium in EP-toxicity leachate (mg/l)
1	4400	25.4	<10	2.44
2	3500	2.6	20	.40
3	3100	2.6	<10	1.27
4	4300	6.0	<10	1.13
5	3200	2.0	<10	.48
6	3300	2.7	<10	.91
7	5500	3.4	<10	.87
8	3400	6.5	<10	.50
9	3500	7.7	<10	.60
9M	2700	9.6	<10	.86
10	3400	5.2	<10	.45
11	1900	0.2	20	0.04
12	3200	0.3	28	0.20
13	3300	0.4	28	0.20
14	4400	3.9	24	0.90
15	4700	20.5	74	3.00
16	4800	3.0	18	0.84
17	6900	17.6	127	3.04
18	5500	9.5	182	2.20
19	5200	14.6	121	2.19
20	6500	74.5	329	7.57

Source: BP Minerals America 1988.

3250g

Table C-6 Performance Data for the Stability of Calcium Arsenate, Manganese Arsenate, and Ferric Arsenate Precipitates

Constituent (units)	Ferric ppt sludge (K084)	Calcium ppt sludge (K084)	Manganese ppt sludge (K084)
BDAT List Metals (mg/kg)			
Antimony	68	55	36
Arsenic	9760	45200	47400
Barium	1.7	23	9.5
Beryllium	<0.1	<0.1	<0.1
Cadmium	9.4	25	20
Chromium	10	3.2	5.3
Copper	37	4.4	6.2
Lead	18	7.8	12
Mercury	0.93	2.2	2.4
Nickel	5.6	1.6	9.2
Selenium	0.16	<0.5	1
Silver	<0.4	<0.4	1.2
Thallium	<1.0	<1.0	<1.0
Vanadium	<3.0	2.9	2.2
Zinc	24	1530	2330
TCLP Extract (ug/l)			
Antimony	<21	439	67
Arsenic	508	2200000	984000
Barium	344	284	319
Beryllium	<1	<1	<1
Cadmium	<3	5120	2640
Chromium	<40	1180	<40
Copper	339	29	26
Lead	<50	<25	<50
Mercury	0.21	4.7	8.1
Nickel	<100	<100	<100
Selenium	<10	<50	<20
Silver	<4	<4	49
Thallium	<10	<10	<10
Vanadium	<3	43	<30
Zinc	1150	25800	20000
Other Analyses (mg/kg)			
TOC	156000	12900	75300
COD	109000	9700	65500
Total Solids (%)	23.5	25.9	26.2
TSS	NA	NA	NA
pH			
Ash Content (%)	13.8	24	19.9
Sulfate	6080	641	5220
Chloride			
Moisture (%)	76.5	74.1	73.8

Source: Alchowiak 1987.

Table C-7 Vitrification Treatment Performance
Data for Slags Containing Arsenic

Arsenic in slag (wt %)	Arsenic in EP-toxicity leachate (mg/l)
0.3	0.007
0.54	0.016
0.77	0.047
2.1	0.448
3.3	0.421
5.2	0.902
9.0	0.337
9.1	0.415
12.4	0.115
13.7	0.308
16.4	0.377
19.4	0.802
20.7	0.846
23.5	1.781

Source: Twidwell and Mehta 1985.

Table C-8 Vitrification/Glassification Treatment Performance Data

Constituent	Sample Set #1		Sample Set #2		Sample Set #3		Sample Set #4		Sample Set #5	
	Total composition (mg/kg)	EP toxicity leachate (mg/l)	Total composition (mg/kg)	EP toxicity leachate (mg/l)	Total composition (mg/kg)	EP toxicity leachate (mg/l)	Total composition (mg/kg)	EP toxicity leachate (mg/l)	Total composition (mg/kg)	EP toxicity leachate (mg/l)
Arsenic	-	-	-	-	-	-	-	--	17	<0.005
Barium	2,500	<0.2	2,500	<0.2	1,230	0.9	2,000	<0.2	3,700	1.2
Chromium	7,200	<0.1	7,200	<0.1	2,900	0.08	-	<0.1	11,000	0.03
Lead	-	<0.02	-	<0.02	0.65	1.1	-	<0.02	-	<0.1

Source: Chapman 1989.

Table C-9 Precipitation Treatment Performance Data for D004 Wastewaters

Sample Set #1

Constituents (units)	Calcium hydroxide precipitation				Manganese sulfate precipitation		Ferric sulfate precipitation	
	Untreated waste tank #1	Effluent waste from tank #1	Untreated waste tank #2	Effluent waste from tank #2	Influent	Effluent	Influent	Effluent
BOAT List Metals (mg/l)								
Antimony	2.9	1.13	3.74	0.838	<0.64	<0.64	<0.64	<0.64
Arsenic	1,260	160	826	388	143	16.3	23.4	0.58
Cadmium	3.98	0.479	2.99	1.34	0.476	<0.080	0.259	<0.08
Lead	2.98	<0.05	0.044	<0.05	0.0053	0.0063	<0.05	0.012
Mercury	0.036	0.026	0.019	0.0064	0.0049	0.0057	0.0086	0.00049
Zinc	1.22	0.061	0.473	0.047	0.047	0.0059	0.178	0.789
Other Analytes (mg/l)								
Total solids	75,800	52,700	38,400	44,900	44,600	43,000	42,400	42,300
Total dissolved solids	54,400	49,800	37,300	40,700	40,000	42,700	41,500	40,500
Total suspended solids	96	84	84	293	68	18	151	30
Chemical oxygen demand	2.84	1,310	836	809	972	972	972	787
Total organic carbon	0.45	392	240	217	351	245	245	201
Operating Parameters								
pH	4.04	12.34	10.94	12.18	12.01	7.02	7.42	3.79

Table C-9 (continued)

Sample Set #2

Constituents (units)	Calcium hydroxide precipitation				Manganese sulfate precipitation		Ferric sulfate precipitation	
	Untreated waste tank #1	Effluent waste from tank #1	Untreated waste tank #2	Effluent waste from tank #2	Influent	Effluent	Influent	Effluent
BDAT List Metals (mg/l)								
Antimony	1.46	1.07	1.09	<0.64	0.7	<0.64	<0.64	<0.64
Arsenic	960	105	427	67.3	147	10.5	35.9	0.247
Cadmium	3.08	0.422	1.09	0.242	0.324	<0.08	0.092	<0.08
Lead	<0.05	0.007	0.075	0.0077	<0.005	0.013	<0.05	0.011
Mercury	0.142	0.123	0.076	0.047	0.038	0.0069	0.0094	0.0038
Zinc	0.749	0.082	1.0	<0.04	0.097	<0.04	0.097	0.900
Other Analyses (mg/l)								
Total solids	39,600	36,700	11,700	12,300	36,500	37,500	48,500	35,700
Total dissolved solids	39,300	59,000	11,100	12,200	35,800	35,800	35,800	36,000
Total suspended solids	96	63	334	14	418	70	344	83
Chemical oxygen demand	1.39	1,250	724	--	1,030	773	980	692
Total organic carbon	0.401	358	221	--	322	226	258	186
Operating Parameters								
pH	2.17	11.96	7.06	12.82	11.8	8.06	7.6	4.17

Table C-9 (continued)

Sample Set #3

Constituents (units)	Calcium hydroxide precipitation				Manganese sulfate precipitation		Ferric sulfate precipitation	
	Untreated waste tank #1	Effluent waste from tank #1	Untreated waste tank #2	Effluent waste from tank #2	Influent	Effluent	Influent	Effluent
BDAT List Metals (mg/l)								
Antimony	4.11	2.04	0.914	<0.64	1.09	0.671	0.695	<0.64
Arsenic	706	279	1,280	142	205	6.02	15.0	0.163
Cadmium	2.59	0.73	3.25	0.416	0.552	<0.080	<0.08	<0.08
Lead	0.078	0.063	0.279	<0.005	<0.005	<0.005	0.0092	0.014
Mercury	0.19	0.114	0.112	0.051	0.044	<0.026	0.028	0.017
Zinc	1.17	0.059	0.617	0.047	0.082	<0.04	0.04	0.699
Other Analyses (mg/l)								
Total solids	22,300	24,900	61,400	56,600	18.700	23,100	21,200	21,400
Total dissolved solids	22,100	20,400	72,500	57,000	17,800	20,700	21,500	20,900
Total suspended solids	117	52	26	161	128	8	97	23
Chemical oxygen demand	1,590	1,410	1,180	1,250	1,130	515	750	442
Total organic carbon	532	450	213	170	341	129	145	116
Operating Parameters								
pH	7.61	12.31	2.01	12.09	12.41	7.34	7.17	4.0

Table C-9 (continued)

Sample Set #4

Constituents (units)	Calcium hydroxide precipitation				Manganese sulfate precipitation		Ferric sulfate precipitation	
	Untreated waste tank #1	Effluent waste from tank #1	Untreated waste tank #2	Effluent waste from tank #2	Influent	Effluent	Influent	Effluent
BDAT List Metals (mg/l)								
Antimony	3.16	0.908	1.59	0.963	<0.64	<0.64	<0.64	<0.64
Arsenic	399	112	1,340	500	125	22.4	26,500	0.204
Cadmium	0.977	0.201	2.86	0.953	0.201	<0.08	<0.08	<0.08
Lead	<0.05	<0.05	0.478	0.0064	0.014	<0.005	<0.02	<0.05
Mercury	0.04	0.016	0.076	0.058	0.022	0.0041	0.011	0.0023
Zinc	0.636	<0.04	0.21	0.04	0.056	0.051	0.05	0.712
Other Analyses (mg/l)								
Total solids	17,400	17,500	62,800	62,000	36,900	37,200	36,800	36,400
Total dissolved solids	14,500	15,000	62,200	59,100	37,200	36,500	37,400	36,500
Total suspended solids	161	7	48	180	184	48	39	69
Chemical oxygen demand	1,990	1,730	1,190	932	1,230	1,070	992	823
Total organic carbon	667	554	232	196	330	233	264	207
Operating Parameters								
pH	12.12	12.85	6.46	11.84	12,35	7.49	7.49	4.12

Table C-9 (continued)

Sample Set #5

Constituents (units)	Calcium hydroxide precipitation				Manganese sulfate precipitation		Ferric sulfate precipitation	
	Untreated waste tank #1	Effluent waste from tank #1	Untreated waste tank #2	Effluent waste from tank #2	Influent	Effluent	Influent	Effluent
BOAT List Metals (mg/l)								
Antimony	3.41	2.26	0.64	<0.64	1.36	<0.64	0.698	<0.64
Arsenic	717	60.5	1,670	174	302	15.3	107	0.224
Cadmium	1.5	0.134	3.64	0.32	0.447	<0.08	0.106	<0.08
Lead	0.197	<0.01	0.371	0.014	<0.005	<0.005	<0.05	<0.025
Mercury	0.139	0.051	3.4	0.0027	0.046	<0.02	0.041	0.00073
Zinc	0.974	<0.04	0.164	0.07	0.056	<0.04	0.098	1.92
Other Analyses (mg/l)								
Total solids	30,100	27,900	84,700	38,200	42,600	44,300	44,300	58,900
Total dissolved solids	29,800	28,100	83,800	33,800	41,600	44,200	44,100	44,000
Total suspended solids	128	193	178	82	423	56	601	70
Chemical oxygen demand	940	833	3,250	982	1,050	843	1,110	651
Total organic carbon	194	225	107	270	301	178	203	140
Operating Parameters								
pH	6.97	11.86	1.79	12.02	11.93	7.02	7.34	3.91

- = No analysis performed.

Source: USEPA 1987b.

Table C-10 Ferric Arsenate Precipitation Treatment Performance Data for Different Iron-to-Arsenic Ratios

Influent arsenic concentration (mg/l)	Effluent arsenic concentration (mg/l)	Molar Fe/As ratio used in precipitation
7492	310	1.0
7492	26	2.0
7492	2.1	4.0
7492	0.23	8.0
7492	<0.05	16.0

Operating conditions:

pH = 5

Source: Krause and Ettel 1985.

Table C-11 Selenium Removal from Wastewaters by Chemical Reduction with Ferrous Ion

Sample	Selenium concentration, (µg/8)	
	Untreated	Treated
1	90	<1
2	85	<1
3	80	<1
4	81	<1
5	79	<1

Source: Murphy 1989.

APPENDIX D

Analytical Methods and Quality Assurance/Quality Control Data

D. ANALYTICAL METHODS AND QUALITY ASSURANCE/QUALITY CONTROL DATA

The analytical methods used for analysis of arsenic and selenium are listed in Table D-1. SW-846 methods (EPA's Test Methods for Evaluation of Solid Waste; Physical/Chemical Methods, SW-846, Third Edition, November 1986) are used in most cases for determining total constituent concentrations. Leachate concentrations were determined using the Extraction Procedure (EP) Toxicity Test method in SW-846.

In some instances, SW-846 allows for the use of alternative or equivalent procedures or equipment. The specific procedures or equipment used for analysis of metal compounds are shown in Table D-2.

All concentrations for the regulated constituents are corrected to account for analytical interference associated with the chemical makeup of the waste matrix. The correction factor for a constituent is based on the matrix spike recovery values. Table D-3 presents the matrix spike recoveries used to determine the correction factor for the EPA-collected D004 wastewater data.

Since no matrix spike recovery values were available for the slag vitrification data, matrix spike recovery values for a similar nonwastewater (i.e., K102 ash TCLP extract) matrix have been used to correct the slag vitrification data. The recoveries used to correct the slag vitrification EP-Tox leachate metal concentrations are shown in Table D-4.

Table D-1 Analytical Methods for Regulated Constituents

Regulated constituent	Analytical method	Method number	Reference
Arsenic	Extraction procedure toxicity test method	1310	1
Arsenic	Acid digestion of aqueous samples and extracts for total metals for analysis by flame atomic absorption spectroscopy (AA) or inductivity coupled plasma atomic emission spectroscopy (ICP)	3010	1
	Acid digestion of aqueous samples and extracts for total metals for analysis by furnace atomic absorption spectroscopy (AA)	3020	1
	Acid digestion of sediments, sludges, and soils	3050	1
	Acid digestion for metals	3060	2
	Inductively coupled plasma atomic emission spectroscopy	6010	1
Selenium	Selenium (AA, furnace technique)	7740	1

1 - Environmental Protection Agency. 1986. Test Methods for Evaluating Solid Waste (SW-846). Third Edition. U. S. EPA. Office of Solid Waste and Emergency Response. November 1986.

2 - Environmental Protection Agency. 1982. Test Methods for Evaluating Solid Waste. Second Edition. U. S. EPA. Office of Solid Waste and Emergency Response. September 1982.

Table D-2 Specific Procedures or Equipment Used in Preparation for Analysis of Metals When Alternatives or Equivalents Are Allowed in the SW-846 Methods

Analysis	SW-846 method	Equipment	Alternative or equivalent allowed by SW-846 methods	Specific procedures or equipment used
Inductively coupled plasma atomic emission spectroscopy	6010	Jarrell Ash 1140	• Operate equipment following instructions provided by instrument's manufacturer.	• Equipment operated using procedures specified in the Jarrell Ash (JA) 1140 Operator's Manual.
			• For operation with organic solvents, auxiliary argon gas inlet is recommended.	• Auxiliary argon gas was not required for sample matrix.
Metals by furnace AA	7841 7740 7421	(1) Perkin Elmer 5000 #1 (2) Perkin Elmer 5000 #2 (3) Perkin Elmer 5000 #3 (4) Perkin Elmer 2580	• Operate equipment following instructions provided by instrument's manufacturer.	• Equipment operated using procedures specified in (1) the Perkin Elmer 3030 Instruction Manual, (2) the Perkin Elmer Model 5000 Instruction Manual, and (3) the Perkin Elmer 2580 Instruction Manual.
			• For background correction, use either continuous correction or alternatives, e.g., Zeeman correction.	• Background detection was used. Continuous correction on Models 2380 and 5000 #2 and Zeeman on Model 3030 and 5000 #1.
			• If samples contain a large amount of organic material, they should be oxidized by conventional acid digestion before being analyzed.	• Samples were prepared using acid digestion procedures from SW-846.

Reference: USEPA 1987b.

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Table D-3 Matrix Spike Recoveries for Treated D004 Waste

BDAT constituent	Original amount found (μg/l)	Sample Set # 1			Sample Set Duplicate 1			Accuracy factor[b]
		Spike added (μg/l)	Spike result (μg/l)	Percent recovery[a]	Spike added (μg/l)	Spike result (μg/l)	Percent recovery[a]	
Metals								
Arsenic	782	2,000	3,640	143	2,000	3,980	160	1.00
Cadmium	<80	500	484	97	500	471	94	1.06
Lead	<5	25	21	84	25	37	148	1.19
Mercury	0.86	5	5.6	95	5	5.6	95	1.05

Reference: USEPA 1987b.

[a] = Percent Recovery = ([(Spike Result - Original Amount)/Spike Amount)] x 100.

[b] = Accuracy Correction Factor = 100/(Percent Recovery), using the lower of the two percent recovery values.

Table D-4 Matrix Spike Recoveries Used to Calculate Correction Factors for the Slag Vitrification EP-Tox Leachate Value

BDAT constituent	Original sample (μg/l)	Spike added (μg/l)	Sample #1 Spike result (μg/l)	Sample #1 Percent recovery[a]	Sample Set Duplicate 1 Spike result (μg/l)	Sample Set Duplicate 1 Percent recovery[a]	Accuracy Correction factor[b]
Arsenic	17,100	10,000	26,100	90	26,100	90	1.11

[a] Percent recovery = [(Spike Result - Original Amount)/Spike Amount] x 100.
[b] Accuracy Correction Factor = 100/Percent Recovery (using the lowest percent recovery values).

Reference: USEPA 1988a.